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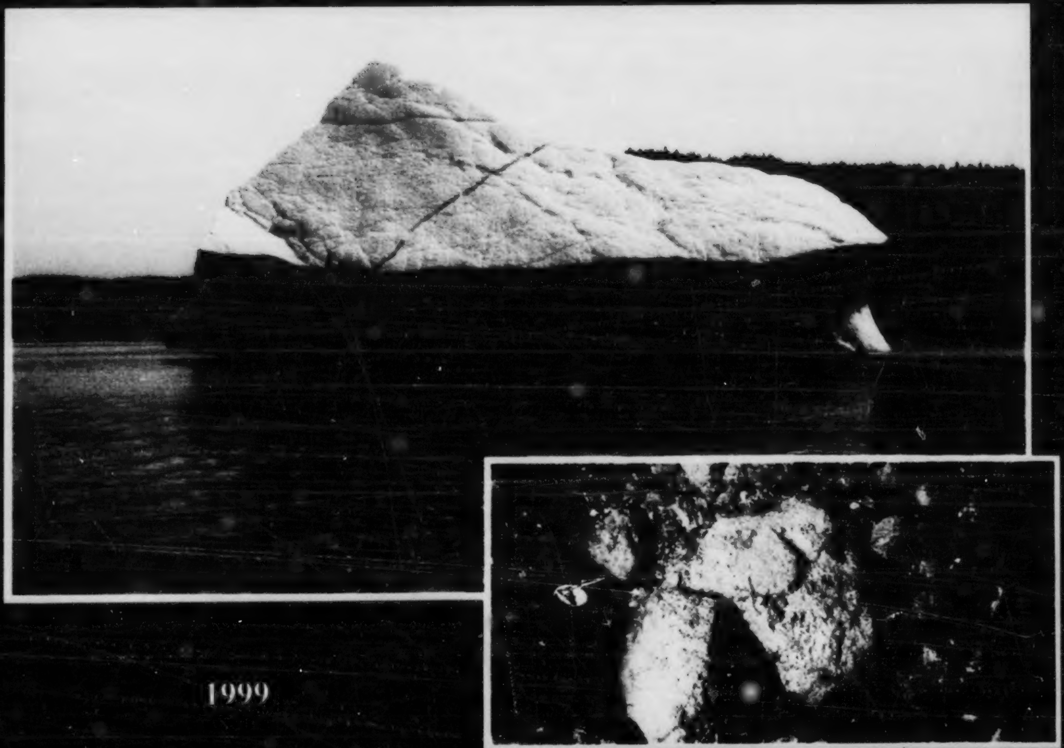
SURFICIAL SEDIMENTS AND PLACER GOLD ON THE INNER SHELF AND COAST OF NORTHEAST NEWFOUNDLAND

J. Shaw, D.L. Forbes, and K.A. Edwardson



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Cover illustration

Grounded iceberg at the mouth of Bay of Exploits. Photograph by J. Shaw (GSC), 14 August 1991. GSC 1999-005A
Inset: Boulders and pebbles on the seabed at a water depth of 60 m, at the mouth of Bay of Exploits. Photograph taken on 14 August 1991 using a camera system devised at the Atlantic Geoscience Centre. GSC sample 91031-079. GSC 1999-005B

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SURFICIAL SEDIMENTS AND PLACER GOLD ON THE INNER SHELF AND COAST OF NORTHEAST NEWFOUNDLAND

Abstract

The inner Northeast Newfoundland Shelf and coast were mapped to determine the potential of the region to host marine placer minerals, particularly gold. Five units were mapped: unit 1, bedrock; unit 2, glacial diamicton; unit 3, glaciomarine mud; unit 4, postglacial mud; and unit 5, postglacial sand and gravel. These units occur in five zones defined by depth, as follows: 1) deep, offshore basins contain thick deposits of glaciomarine, gravelly, sandy mud overlain by postglacial mud; 2) in shallower water, these units have been winnowed by currents; 3) above a depth of about 200 m, the seabed has been furrowed and pitted by grounded icebergs; 4) above a depth of 70 m the seabed is highly mobile; 5) the intertidal/supratidal zone is narrow and rocky, except along The Straight Shore. Relative sea level has been falling throughout postglacial time in the west, but in the east it dropped to -20 m about 8.7 ka before rising again. Fiords contain thick deposits of glaciomarine mud, capped by thin, postglacial mud. Shallow, outer-fiord areas are heavily imprinted by iceberg furrows and pits. In zone 4, which has the highest potential to host marine placers, extensive gravel and sand deposits occur on the wide, shallow, inner shelf between Cape Freels and Hamilton Sound, but no gold has been found in samples, likely because of a lack of gold mineralization onshore. Some gold was found at Deer Cove in Baie Verte, although the volume is small and the grades low.

Résumé

Les zones littorales et la partie interne de la plate-forme nord-est de Terre-Neuve ont été cartographiées dans le but de déterminer le potentiel d'y découvrir des minéraux de placers marins, en particulier de l'or. Cinq unités ont ainsi été cartographiées : l'unité 1, le substratum rocheux; l'unité 2, un diamicton glaciaire; l'unité 3, une boue glaciomarine; l'unité 4, une boue postglaciaire; et l'unité 5, du sable et gravier postglaciaires. Ces unités se rencontrent dans cinq zones définies selon leur profondeur : 1) des bassins extracôtiers profonds contenant des dépôts épais de boue glaciomarine graveleuse et sableuse recouverte de boue postglaciaire; 2) en eau moins profonde, ces unités ont été vannées par les courants; 3) à moins d'environ 200 m de profondeur, des icebergs échoués ont creusé des sillons et des dépressions dans le fond marin; 4) à moins de 70 m de profondeur, le fond marin comporte des sédiments très mobiles; 5) la zone intertidale/supratidale est étroite et rocailleuse, sauf le long du littoral dit The Straight Shore. Dans l'ouest, le niveau marin relatif a chuté pendant toute la période postglaciaire; par contre, dans l'est, il a chuté à -20 m vers 8,7 ka pour ensuite remonter. Les fjords contiennent des dépôts épais de boue glaciomarine sur lesquels reposent de minces dépôts de boue postglaciaire. Les zones peu profondes de l'entrée des fjords sont fortement marquées par des sillons et des dépressions creusés par des icebergs. Dans la zone 4, qui offre le potentiel le plus élevé de receler des placers marins, de vastes dépôts de sable et de gravier recouvrent la plate-forme interne large et peu profonde entre le cap Freels et la baie Hamilton, mais les échantillons ne renfermaient pas d'or, probablement à cause d'une absence de minéralisation aurifère sur terre. De l'or a été découvert à l'anse Deer dans la baie Verte, mais le volume est petit et les teneurs sont faibles.

SUMMARY

This report summarizes the results of a multiyear mapping program on the inner shelf and coasts of northeast Newfoundland, funded under the Canada–Newfoundland Co-operation Agreement on Mineral Development. Its purpose was to map the distribution of surficial sediments and the abundance of placer minerals, particularly gold. This region was selected on the basis of a report produced for the provincial government by C-CORE (Centre for Cold Ocean Resources Engineering, Memorial University of Newfoundland). It was hoped that, in addition to giving an initial evaluation of marine placer potential, a mapping project would provide essential baseline geological data for a region whose marine geology was relatively unknown.

The principal geomorphic feature of the inner Northeast Newfoundland Shelf is the northeast-trending Notre Dame Channel, which has a maximum depth of 406 m. The coastal fringe shallower than 200 m is extensive in only two areas, off the north and northeast coasts of Baie Verte Peninsula and in the Fogo Island–Cape Freels region, where the 100 m isobath extends an average of 25 km offshore, forming the greatest extent of shallow water in the study area. The coastline is interrupted by a series of north- to northeast-trending, glacially overdeepened, silled, coastal basins, as follows: White Bay (maximum depth 536 m, sill depth about 280 m); Baie Verte (324 m, 192 m); Green Bay (411 m, about 280 m); Halls Bay (490 m, 250 m); a basin east of Long Island (536 m, 290 m); Badger Bay (525 m, 290 m); and New Bay (439 m, about 200 m). Bay of Exploits contains two deep troughs, a western one (673 m, about 210 m) and an eastern one (604 m, 250–300 m). East of Bay of Exploits, the major coastal troughs are absent whereas shallow (<100 m), silled basins are common.

Onshore, the study area contains elements of three of the four tectonic zones of Newfoundland: 1) the Humber Zone lies west of the Baie Verte–Brompton Line and contains a basement of continental crust, metamorphosed and intruded during the Middle Proterozoic; 2) east of the Humber Zone, the Dunnage Zone is characterized by Cambrian to Middle Ordovician submarine volcanic rocks and early Ordovician ophiolite suites; 3) the Gander Zone lies east of the 'Grub Line' and contains quartz-rich, siliciclastic, sedimentary rocks of probable Cambrian and Ordovician age, with Devonian and Carboniferous granite intrusions at the coast. The zone boundaries, deep crustal block boundaries, and faults trend northeast, imposing a strong structural grain that is reflected in the orientation of valleys and coastal embayments. This structural grain is also imparted to the bedrock geology offshore, where major faults trend northeast.

SOMMAIRE

Le présent rapport est un résumé des résultats d'une campagne pluriannuelle de cartographie de la plate-forme continentale interne et des zones littorales du nord-est de Terre-Neuve. Cette campagne a été financée dans le cadre de l'Entente de coopération Canada–Terre-Neuve sur l'exploitation minière. Il s'agissait de cartographier la répartition des sédiments superficiels et l'abondance des minéraux de placers, en particulier de l'or. Le choix de cette région repose sur un rapport produit pour le gouvernement provincial par C-CORE (Centre for Cold Ocean Resources Engineering, Memorial University of Newfoundland). On espérait qu'en plus de permettre une évaluation initiale du potentiel des placers marins, ce projet fournirait les données géologiques de base d'une région dont la géologie sous-marine était relativement peu connue.

La principale entité géomorphologique de la partie interne de la plate-forme nord-est de Terre-Neuve est le chenal Notre Dame, à direction nord-est, dont la profondeur maximale est de 406 m. La bande littorale de moins de 200 m de profondeur n'est vaste que dans deux zones, au large des côtes nord et nord-est de la péninsule Baie Verte et dans la région de l'île Fogo et du cap Freels, là où l'isobathe de 100 m s'étend jusqu'à 25 km en moyenne au large, formant la plus grande étendue d'eau peu profonde de la région à l'étude. Le littoral est interrompu par une série de bassins littoraux fermés par une crête et surcreusés par les glaces, à direction nord à nord-est, soit la baie White (profondeur maximale de 536 m, profondeur de la crête d'environ 280 m), la baie Verte (324 m, 192 m), la baie Green (411 m, 280 m environ), la baie Halls (490 m, 250 m), un bassin à l'est de l'île Long (536 m, 290 m), la baie Badger (525 m, 290 m) et la baie New (439 m, quelque 200 m). La baie des Exploits comporte deux dépressions profondes, une à l'ouest (673 m, quelque 210 m) et une autre à l'est (604 m, 250–300 m). À l'est de la baie des Exploits, les dépressions littorales importantes sont inexistantes, mais les bassins fermés peu profonds (< 100 m) sont nombreux.

Sur la terre ferme, la région à l'étude se compose de certains éléments de trois des quatre zones tectoniques de Terre-Neuve : 1) la Zone de Humber s'étend à l'ouest de la Faille de Baie Verte–Brompton et comporte un socle de croûte continentale, métamorphisé et intrudé au Protérozoïque moyen; 2) à l'est de la Zone de Humber, la Zone de Dunnage se caractérise par des roches volcaniques sous-marines du Cambrien à l'Ordovicien moyen et par des suites ophiolitiques de l'Ordovicien précoce; 3) la Zone de Gander, située à l'est de la «Faille de Grub», contient des roches sédimentaires silicoclastiques quartzifères d'âge cambrien et ordovicien probable et des intrusions de granite dévonien et carbonifère sur la côte. Les limites de la zone et des blocs crustaux profonds ainsi que les failles sont orientées nord-est, ce qui donne à la région un grain structural marqué représenté par l'orientation des vallées et des baies littorales. Ce grain structural se manifeste également dans la géologie du substratum rocheux au large, là où les failles majeures ont une direction nord-est.

Gold has been recovered at a number of sites and is the target of continued exploration activity. Two styles of mineralization occur: epigenetic vein and epithermal deposits in which gold is the primary target and volcanogenic massive sulphide mineralization with which gold is often associated. Epigenetic gold is found in veins associated with major faults and lineaments on Baie Verte Peninsula at Nugget Pond, Goldenville, Pine Cove, Stog'er Tight, and Deer Cove. Several occurrences are in the northeastern Dunnage Zone, around Gander Bay and Dog Bay. Gold content is low in massive sulphide deposits, the second mineralization style. Most volcanogenic massive sulphide deposits on Baie Verte Peninsula are in ophiolitic sequences, including the Tilt Cove, Betts Cove, Consolidated Rambler, and Terra Nova deposits. In the Halls Bay area, sulphide deposits in the Lushes Bight Group ophiolites contain local, minor concentrations of gold. Gold has been recovered from the Little Bay and Miles Cove deposits.

Five principal seismostratigraphic units have been mapped; their distribution is shown on Figure 1 (in pocket). Unit 1 (bedrock) is acoustic basement in most areas, although low-frequency, seismic reflection profiles of Paleozoic rocks display some acoustic structure. In the zone described as 'bedrock predominant' on Figure 1, bedrock typically has thin (<1 m), discontinuous veneers of mud or sandy mud, with patches of ice-rafted, angular gravel, or sand and gravel.

Unit 2 commonly overlies unit 1 and consists of glacial diamicton and other deposits formed in contact with Late Wisconsinan glacier ice. On seismic reflection profiles, unit 2 has a dark, uniform tone formed by incoherent reflections. Unit 2 has positive relief and forms mounds, ridges, wedge-shaped sheets, cross-valley ridges (Bay of Exploits and Baie Verte), and drumlins (Hamilton Sound). East of Baie Verte Peninsula, debris-flow deposits from a ridge of unit 2 sediment interfinger with stratified, glaciomarine sediments. At water depths above 200 m, the surface of unit 2 has been furrowed and pitted by iceberg impact. Unit 2 is exposed over extensive areas of the seabed well offshore from the coast in the central and eastern parts of the study region. Cores show that unit 2 is a diamicton consisting of randomly oriented, subangular pebbles in a matrix of sandy, silty clay. It is equivalent to the Newfoundland Shelf Drift mapped on the western Grand Banks by Fader et al. (1982).

De l'or a été récupéré à de nombreux sites et il continue d'être la cible d'activités d'exploration. On observe deux styles de minéralisation : gisements filoniens épigénétiques et épithermaux dans lesquels l'or est la cible principale et sulfures massifs volcanogènes auxquels l'or est souvent associé. L'or épigénétique est présent dans des filons associés à des failles et linéaments majeurs dans la péninsule Baie Verte au lac Nugget Pond, à Goldenville, à l'anse Pine, à Stog'er Tight et à l'anse Deer. Plusieurs occurrences se rencontrent dans le nord-est de la Zone de Dunnage, à proximité des baies Gander et Dog. La teneur en or est faible dans les sulfures massifs, qui représentent le deuxième style de minéralisation. La plupart des gisements de sulfures massifs volcanogènes dans la péninsule Baie Verte logent dans des séquences ophiolitiques, notamment les gîtes de Tilt Cove, de Betts Cove, de Consolidated Rambler et de Terra Nova. Dans la région de la baie Halls, les gisements de sulfures dans les ophiolites du Groupe de Lushes Bight renferment des concentrations mineures locales d'or. On a récupéré de l'or dans les gisements de Little Bay et de Miles Cove.

Cinq unités sismostratigraphiques principales ont été cartographiées; la figure 1 (en pochette) montre leur répartition. L'unité 1 (substratum rocheux) est un socle acoustique dans la plupart des régions, bien que des profils de sismique-réflexion de basse fréquence de roches paléozoïques affichent une certaine structure acoustique. Dans la zone décrite à la figure 1 comme étant surtout composée de substratum rocheux, le substratum rocheux est typiquement recouvert de minces (< 1 m) placages discontinus de boue ou de boue sableuse ponctués d'îlots de gravier anguleux ou de sable et gravier transportés par les glaces.

L'unité 2 recouvre habituellement l'unité 1 et se compose de diamicton glaciaire et d'autres dépôts formés par contact avec la glace glaciaire du Wisconsinien supérieur. Sur les profils de sismique-réflexion, l'unité 2 est caractérisée par une teinte sombre et uniforme créée par des réflexions incohérentes. L'unité 2 présente un relief positif formé de monticules, de crêtes, de nappes en biseau, de crêtes perpendiculaires à des vallées (baie des Exploits et baie Verte) et de drumlins (baie Hamilton). À l'est de la péninsule Baie Verte, des dépôts de coulées de débris provenant d'une crête de sédiments de l'unité 2 s'interdigitent avec des sédiments glaciomarins stratifiés. À des profondeurs océaniques de moins de 200 m, la surface de l'unité 2 est marquée de sillons et de dépressions creusés par des icebergs. L'unité 2 affleure sur de vastes étendues du fond océanique bien au large dans les parties centrale et orientale de la région à l'étude. Les carottes révèlent que l'unité 2 est un diamicton contenant des cailloux subanguleux orientés au hasard dans une matrice d'argile sableuse et silteuse. Ce diamicton est équivalent au Drift de Newfoundland Shelf cartographié dans la partie ouest des Grands Bancs par Fader et al. (1982).

Unit 3, commonly found above unit 2, is glaciomarine, hemipelagic sediment deposited by turbidity currents, debris flows, and fallout from meltwater plumes. It occurs as three acoustic facies. Facies 1 contains moderate- to high-intensity, continuous, coherent reflections that are highly conformable to the underlying terrain, as well as scattered, point-source reflections. It has an average thickness of about 5 m and is interpreted as a glaciomarine, hemipelagic sediment deposited by glacial meltwater plumes. Facies 2 occurs mainly within fiords as thick (150 m) basin-fill deposits in which acoustically transparent intervals up to 20 m thick are interleaved with stratified sediments similar in appearance to facies 1. Facies 2 is interpreted as glaciomarine, hemipelagic sediment deposited by turbidity currents, debris flows, and meltwater plumes close to the margin of Late Wisconsinan glacier ice. Facies 3 occurs towards the heads of fiords and comprises stratified sediments similar in appearance to facies 2, but is contorted due to movement along slip planes and slumping. Unit 3 is equivalent to the Emerald Silt Formation on the Scotian Shelf (King and Fader, 1986) or the Downing Silt Formation on the Newfoundland Shelf (Fader and Miller, 1986).

Unit 4 is postglacial mud. In an early phase, it was deposited by ice rafting and from meltwater plumes emanating from distant fiord glaciers, resulting in strong, closely spaced, parallel, internal reflections. Later, it was formed by reworking of units 2 and 3 by waves and currents, which made it acoustically transparent. In shallower areas, the top of the unit has been removed, presumably by current action, producing an angular unconformity at the seabed. Thick deposits of unit 4 occur in the deepest basins, principally Notre Dame Basin (up to 45 m). Unit 4 is relatively thin in fiords, where it is often banked against either of the sidewalls.

Unit 5 is sand and gravel formed through reworking of older units by waves and currents. Where the sand is fine and has a high mud content, it has some acoustic stratification (e.g. in Hamilton Sound), but coarser grain sizes inhibit penetration by subbottom profilers. Unit 5 includes the following: well sorted sand with shell hash and scattered pebbles, with wave- and current-formed bedforms; thin sheets of mobile, poorly sorted, sandy gravel, with ripples; thin veneers of largely immobile (*Lithothamnion*-coated) gravel overlying glacial diamicton; and shoreface prisms of sand or muddy sand that pass laterally into beaches. It occurs as a littoral fringe,

L'unité 3, fréquemment présente au-dessus de l'unité 2, se compose de sédiments glaciomarins hémipélagiques déposés par des courants de turbidité, des coulées de débris et des panaches d'eau de fonte. Elle forme trois faciès acoustiques. Le faciès 1 comporte des réflexions cohérentes et continues d'intensité moyenne à élevée qui sont en concordance marquée avec le terrain sous-jacent ainsi que des réflexions disséminées de sources ponctuelles. Son épaisseur moyenne est d'environ 5 m et il s'agirait de sédiments glaciomarins hémipélagiques déposés par des panaches d'eau de fonte. Le faciès 2 se retrouve surtout dans les fjords où il forme des dépôts épais (150 m) de remplissage de bassins dans lesquels des intervalles transparents aux ondes acoustiques et mesurant jusqu'à 20 m d'épaisseur sont intercalés de sédiments stratifiés dont l'apparence se rapproche de celle du faciès 1. Le faciès 2 serait constitué de sédiments glaciomarins hémipélagiques déposés par des courants de turbidité, des coulées de débris et des panaches d'eau de fonte à proximité de la marge de la glace glaciaire du Wisconsinien supérieur. Le faciès 3 se rencontre au fond de fjords et se compose de sédiments stratifiés qui ressemblent à ceux du faciès 2, mais qui sont déformés par un mouvement le long de plans de glissement et par effondrement. L'unité 3 est équivalente à la Formation d'Emerald Silt sur la plate-forme Néo-Écossaise (King et Fader, 1986) ou à la Formation de Downing Silt sur la plate-forme de Terre-Neuve (Fader et Miller, 1986).

L'unité 4 est une boue postglaciaire. Pendant une phase précoce, elle a été déposée à partir de radeaux de glace et de panaches d'eau de fonte provenant de glaciers de fjord éloignés, ce qui a produit de fortes réflexions internes, parallèles, étroitement espacées. Plus tard, elle a été formée par le remaniement des unités 2 et 3 par les vagues et les courants, ce qui l'a rendue transparente aux ondes acoustiques. Dans les régions moins profondes, le sommet de l'unité a été enlevée, probablement par des courants, produisant une discordance angulaire au niveau du fond océanique. Des dépôts épais de l'unité 4 sont présents dans les bassins les plus profonds, principalement dans le bassin Notre Dame (jusqu'à 45 m). L'unité 4 est relativement mince dans les fjords où elle est souvent adossée contre l'une ou l'autre des parois.

L'unité 5, composée de sable et gravier, est le produit du remaniement d'unités plus anciennes par des vagues et des courants. Là où le sable est fin et contient une forte teneur en boue, on observe une certaine stratification acoustique (p. ex. dans la baie Hamilton), mais les granulométries plus grossières empêchent la pénétration par les profileurs subocéaniques. L'unité 5 est constituée de sable bien trié contenant des débris de coquillages et des cailloux épars et dont la surface a été modelée par les vagues et les courants; de minces nappes de gravier sableux, mobile, mal trié, avec des rides; de minces placages de gravier largement immobile (enrobé de *Lithothamnion)* reposant sur du diamicton glaciaire; et de prismes de sable ou de sable boueux d'avant-plage qui se mainly within the present wave base. The most extensive areas of unit 5 are in the northeast, off The Straight Shore and in Hamilton Sound.

Glaciers likely extended across the modern coast and onto the shelf beyond the study area, since unit 2 extends towards the shelf edge. There are no data from this study to prove that the ice was Late Wisconsinan. Ridges of glacial diamicton along the flanks of Notre Dame Channel (east of Baie Verte Peninsula) are interpreted as Late Wisconsinan grounding lines. Radiocarbon-dated marine pelecypods from unit 3 (glaciomarine mud) show that Late Wisconsinan ice had retreated to the present coast by 13 ka. Ablating ice formed marine deltas of coarse-grained material at the heads of fiords and discharged turbid plumes for several thousand years, forming thick deposits of unit 3 in fiord basins. When ice was at the heads of the fiords, the postglacial mud of unit 4 deposited in basins contained ice-rafted debris, which imparted moderate acoustic stratification. With the disappearance of the ice, the primary source of postglacial mud in basins was reworking by waves and currents, and the unit became acoustically transparent.

During and after ice retreat, relative sea level dropped from the marine limit (which was over 100 m above present sea level in White Bay and about 40 m in Hamilton Sound). In the west, it is not known to have dropped below the present level. In the east (Hamilton Sound and Cape Freels areas), it had fallen to about -17 m by approximately 8–9 ka, before rising to the present level.

Quaternary sediments have been impacted by icebergs, so that in water depths of 90–200 m, the seabed commonly is furrowed and pitted. Heavily impacted areas include the region immediately north of Baie Verte Peninsula, the outer parts of small fiords (e.g. Little Bay), and around Fogo Island. The degree to which seabed morphology reflects modern iceberg activity is unclear, although observations made during this study suggest that groundings are frequent in the shallowest areas.

The coastal geomorphology is described in terms of six coastal types: 1) exposed, rocky, low coast with sandy beaches and dunes, mainly between Cape Freels and Hamilton Sound; 2) exposed, rocky, low- to high-relief coast with cliffs, wave-washed rock ramps, and limited beach development, dominant on the outer coast

transforment latéralement en plages. Elle forme une frange littorale, principalement dans la zone du niveau de base des vagues. Les étendues les plus vastes de l'unité 5 se trouvent au nord-est, au large du littoral dit The Straight Shore et dans la baie Hamilton.

Il est probable que les glaciers s'étendaient sur la côte actuelle et sur la plate-forme continentale au-delà de la région à l'étude, puisque l'unité 2 se prolonge vers le rebord de la plate-forme continentale. Aucune donnée de la présente étude n'indique que les glaces remontaient au Wisconsinien supérieur. Les crêtes de diamicton glaciaire qui longent les flancs du chenal Notre Dame (à l'est de la péninsule Baie Verte) sont interprétées comme des lignes d'ancrage du Wisconsinien supérieur. Des pélécypodes marins tirés de l'unité 3 (boue glaciomarine) et datés au radiocarbone indiquent que les glaces du Wisconsinien supérieur s'étaient retirées jusqu'à la côte actuelle dès 13 ka. Les glaces en ablation ont formé des deltas marins composés de sédiments à grain grossier au fond des fjords et ont produit des panaches turbides pendant plusieurs milliers d'années, d'où la présence de dépôts épais de l'unité 3 dans les bassins des fjords. Lorsque les fonds de fjords étaient englacés, la boue postglaciaire de l'unité 4 déposée dans les bassins contenait des débris transportés par la glace qui sont à l'origine d'une stratification acoustique modérée. Après la disparition des glaces, la source première de la boue postglaciaire dans les bassins a été le remaniement par les vagues et les courants; c'est ainsi que l'unité est devenue transparente aux ondes acoustiques.

Pendant et après le recul des glaces, le niveau relatif de la mer a chuté par rapport à la limite marine (qui était de plus de 100 m au-dessus du niveau marin actuel dans la baie White et d'environ 40 m dans la baie Hamilton). Dans l'ouest, le niveau marin n'aurait pas chuté au-dessous du niveau actuel. Dans l'est (baie Hamilton et cap Freels), le niveau a baisé à environ -17 m dès 8 à 9 ka environ avant de remonter jusqu'au niveau actuel.

Les sédiments quaternaires ont été déformés par les icebergs. C'est pourquoi les fonds se trouvant entre 90 et 200 m de profondeur sont fréquemment marqués de sillons et de dépressions. Les zones fortement touchées sont notamment la région située juste au nord de la péninsule Baie Verte, l'entrée de petits fjords (p. ex. la baie Little) et autour de l'île Fogo. Il n'est pas clair dans quelle mesure la morphologie du fond marin reflète l'activité des icebergs de l'ère moderne. Des observations faites durant la présente étude incitent toutefois à supposer que les échouages sont fréquents dans les régions les moins profondes.

La géomorphologie littorale est décrite en fonction de six types de côte : 1) côte basse, rocheuse, exposée, qui se rencontre principalement entre le cap Freels et la baie Hamilton et où s'étendent des plages sableuses et des dunes de sable; 2) côte rocheuse exposée, faiblement à fortement accidentée, caractérisée par des falaises, des rampes rocheuses soumises à

of most regions; 3) semiexposed, rock-dominated island and outer-fiord coast with rock platforms, rock cliffs, and limited beach development; 4) semiexposed to protected, rock-dominated fiord coast with limited development of mixed sand and gravel beaches; 5) partly exposed to protected, rock-dominated, low-relief coast with extensive rock and boulder platforms, boulder flats, and locally extensive mixed sand and gravel beaches, very extensive in southern Hamilton Sound and Gander Bay; and 6) protected, rock-dominated, low-relief, shallow embayments with extensive boulder flats, found on the northwest side of Bonavista Bay, in Hamilton Sound, Gander Bay, and Dog Bay, and elsewhere.

Modern marine and coastal environments in the study area can be zoned according to depth, which is the principal control on processes currently shaping the seafloor: waves, currents, and iceberg impact. Each depth-dependent zone has a different potential to host gold placers.

Zone 1 comprises the deep basins on the inner shelf, in which sedimentation has probably been continuous since deglaciation, so that relatively thick deposits of postglacial mud (unit 4) overlie stratified, glaciomarine sediment (unit 3). Samples were generally not collected in this zone because it was assumed that it had little potential to host marine placers. However, heavy-mineral concentrate from two samples collected in the fiord basin of Baie Verte contained gold: sample 90013-043 (157 m, 91 ppb) and sample 90013-045 (242 m, 870 ppb).

Zone 2, the basin transition zone, is shallower than zone 1. Its water depth is less than 370 m in White Bay and less than 300 m in Notre Dame Bay. Postglacial sediments have been winnowed by currents, resulting in a surface layer enriched in gravel. In principle, there is potential for enhanced levels of gold in the muddy surface gravels, but the low concentrations of gold in the source sediments and the water depth combine to reduce the potential for economic marine gold placers to almost zero.

Zone 3, the iceberg-impacted zone, is shallower than 200 m. The seabed is commonly imprinted with furrows and pits. Furrows predominate in deeper areas and pits are concentrated at the inner boundary of the zone. Iceberg turbates occur, particularly at the shallower end of the depth range. The winnowing that results from disturbance of the seabed by icebergs theoretically enhances the potential for concentration of heavy mineral and fine gold particles. However, the initial concentration of gold in the glaciomarine muds that are commonly disturbed is very low, the enhancement is probably extremely minor,

l'action des vagues et un nombre limité de plages, qui se rencontre sur la côte externe de la plupart des régions; 3) côte rocheuse semi-exposée d'île et d'entrée de fjords, avec des plates-formes rocheuses, des falaises rocheuses et un nombre limité de plages; 4) côte de fjord principalement rocheuse, semi-exposée à protégée, avec un nombre limité de plages de sable et de gravier mélangés; 5) côte à faible relief, principalement rocheuse, partiellement exposée à protégée, avec de vastes plates-formes de roches et de blocs, des estrans blocailleux et, par endroits, de vastes plages de sable et de gravier mélangés, qui est très répandue dans le sud de la baie Hamilton et la baie Gander; et 6) baies peu profondes à faible relief, principalement rocheuses et avec de vastes estrans blocailleux, qui se rencontrent dans le nord-ouest de la baie Bonavista, dans la baie Hamilton, la baie Gander et la baie Dog, et ailleurs.

Les milieux marins et littoraux modernes dans la région à l'étude peuvent être divisés en zones selon la profondeur, principal facteur agissant sur les processus qui modifient actuellement la morphologie du fond océanique : vagues, courants et échouage d'icebergs. Chacune de ces zones, définies en fonction de la profondeur, offre un potentiel différent de receler des placers aurifères.

La zone 1 inclut les bassins profonds de la plate-forme continentale interne où la sédimentation n'a probablement pas cessé depuis la déglaciation. C'est pourquoi des dépôts relativement épais de boue postglaciaire (unité 4) reposent sur des sédiments glaciomarins stratifiés (unité 3). En général, on n'a pas prélevé d'échantillons dans cette zone du fait que l'on supposait que le potentiel d'y découvrir des placers était peu élevé. Cependant, des concentrés de minéraux lourds tirés de deux échantillons provenant du bassin du fjord de la baie Verte contenaient de l'or : l'échantillon 90013-043 (157 m, 91 ppb) et l'échantillon 90013-045 (242 m, 870 ppb).

La zone 2, zone de transition des bassins, est moins profonde que la zone 1. La profondeur de l'eau y est inférieure à 370 m dans la baie White et à 300 m dans la baie Notre Dame. Les sédiments postglaciaires y ont été vannés par les courants, d'où une couche superficielle enrichie en gravier. En principe, il existe un potentiel de trouver des teneurs plus élevées d'or dans les graviers boueux superficiels, mais les faibles concentrations d'or dans les sédiments d'origine et la profondeur de l'eau concourent à quasi éliminer tout potentiel d'y découvrir des placers aurifères marins rentables.

La zone 3, zone d'échouage des icebergs, ne dépasse pas 200 m de profondeur. Le fond marin est fréquemment marqué par des sillons et des dépressions. Les sillons dominent dans les régions plus profondes et les trous sont concentrés à la limite interne de la zone. Les sédiments perturbés par des icebergs sont présent surtout à faible profondeur. En théorie, le vannage causé par la perturbation du fond océanique par les icebergs augmente le potentiel de concentration de minéraux lourds et de particules fines d'or. Cependant, la concentration initiale d'or dans les boues glaciomarines fréquemment perturbées est très faible, l'accroissement du potentiel est

and the zone is too deep for exploitation. Therefore the potential for economic marine gold placers is low, as evidenced by the levels of gold that were below detection limits in three samples (068, 069, and 070) collected off La Scie during CSS *Hudson* survey 90013.

Zone 4, the wave- and current-dominated zone, extends from a depth of about 60 m to the coast (the zone is deeper in some areas). It is several kilometres wide off La Scie, for example, and 20 km wide off The Straight Shore. Sediments on the seabed are mobilized by wave action. Asymmetrical tidal currents probably act to provide a net transport direction. Icebergs can impact the seabed in this zone, but the resulting pits and furrows are probably soon obliterated by wave action. Areas of mobile, clastic sediments have bedforms such as gravel ripples, sand dunes, and sand ribbons. Elsewhere, poorly sorted boulder-pebble-cobble gravels form intermittently mobile, armoured lags over glacial diamicton or on top of pockets of finer sediment.

Zone 4 is the principal zone for the formation of marine placers. The potential source materials are most likely glacial diamicton and other ice-contact deposits, glaciomarine mud, and (less likely) bedrock. The potential for reworking of this material is greatest in the shallowest areas. As a rule, sufficient energy to significantly rework glacial diamicton is found only in the intertidal zone; in deeper water, reworking by waves results in the formation of an immobile, armoured lag of boulders and cobbles that arrests the winnowing process. In the east, where sea level was lower in the early Holocene, reworking of glacial diamicton could have occurred in a coastal fringe that extends down to 20 m below present sea level; in the west, there has been no reworking below present sea level.

Although the high wave energy and the sea-level history are favourable for placer development off the shallow, exposed northeast coast (The Straight Shore), the lack of glacigenic sediments in the coastal zone and the absence of gold in those sediments where they do occur indicate that large gold placer deposits are unlikely to be found. Of 20 samples from survey 90035 that were assayed, only one (sample 90035-033), from a depth of 28 m in Hamilton Sound, contained gold (52 ppb); it also contained some particulate gold in the sand fraction. A local bedrock source is suggested. Four samples from Gander Bay and five from Dog Bay were collected in

probablement très faible et la zone est trop profonde pour être exploitée. Par conséquent, le potentiel d'y trouver des placers aurifères rentables est peu élevé, comme l'indiquent les concentrations d'or en-deçà des limites de détection dans trois échantillons (068, 069 et 070) prélevés au large de La Scie au cours du levé 90013 effectué à bord du n.s.c *Hudson*.

La zone 4, zone surtout soumise à l'action des vagues et des courants, s'étend entre une profondeur d'environ 60 m et la côte (la zone est, par endroits, plus profonde). Elle mesure plusieurs kilomètres de largeur au large de La Scie et 20 km de largeur au large du littoral dit The Straight Shore. Les sédiments qui reposent sur le fond marin sont mobilisés par les vagues. Des courants de marée asymétriques produisent probablement un transport à direction nette. Les icebergs peuvent échouer sur le fond dans cette zone, mais les dépressions et les sillons ainsi formés sont probablement vite oblitérés par l'action des vagues. Les zones de sédiments clastiques meubles sont modelées par des rides de gravier, des dunes de sable et des rubans sablonneux. Ailleurs, les graviers de blocs-cailloux-galets mal triés forment des pavages, par endroits meubles, sur un diamicton glaciaire ou sur des pochettes de sédiments plus fins.

La zone 4 est la principale zone de formation des placers marins. Les matériaux d'origine sont fort probablement du diamicton glaciaire et d'autres dépôts de contact glaciaire, des boues glaciomarines et (moins probable) le substratum rocheux. C'est probablement dans les zones les moins profondes que le remaniement est le plus important. Règle générale, la zone intertidale est la seule zone où l'énergie est suffisante pour remanier significativement le diamicton glaciaire; en eau plus profonde, le remaniement par les vagues provoque la formation d'un pavage de blocs et de galets qui stoppe le vannage. Dans l'est, où le niveau de la mer était plus bas à l'Holocène inférieur, le remaniement du diamicton glaciaire a pu se produire dans une frange littorale qui descendait jusqu'à 20 m au-dessous du niveau marin actuel; dans l'ouest, il n'y a pas eu de remaniement sous le niveau marin actuel.

Bien que la forte énergie des vagues et l'histoire des fluctuations du niveau marin soient favorables à l'accumulation de placers au large de la côte nord-est peu profonde et exposée (The Straight Shore), l'absence de sédiments d'origine glaciaire dans la zone littorale et l'absence d'or dans ces sédiments, là où ils se trouvent, indiquent qu'il est peu probable d'y découvrir des placers aurifères de grande taille. Des 20 échantillons analysés, provenant du levé 90035, un seul (90035-033), prélevé à une profondeur de 28 m dans la baie Hamilton, contenait de l'or (52 ppb); il contenait en outre quelques particules d'or dans la fraction sableuse. Un substratum rocheux local est proposé comme source. On a recueilli de this zone. One Gander Bay sample (92301-031B), from 2 m water depth off Victoria Cove, contained a small amount of gold (44.9 ppb head grade).

One of three samples collected off La Scie during cruise 90035 contained gold in the mud fraction (sample 136, a gravelly sand from a water depth of 83 m, 684 ppb); it also contained particulate gold. Of seven samples from CSS *Dawson* cruise 91026, six contained over 5 ppb Au in the mud fraction and two of these had relatively high values (sample 026, sand with a surface layer of gravel, water depth 66 m, 109 ppb; and sample 027, fine sand, water depth 77 m, 249 ppb). All six also contained particulate gold. Two samples from CSS *Parizeau* cruise 92042 were analyzed and found to contain only traces of gold, none of which was visible. The sources of these small amounts of gold off La Scie were either glaciomarine sediments that had been winnowed by waves and iceberg impact or mineralized bedrock.

Baie Verte is the most favourable area for marine placer gold. Gold was first detected in samples from CSS *Hudson* cruise 90013. Eleven samples were analyzed, seven of which had detectable (>5 ppb) gold in a heavy-mineral concentrate, including sample 90013-042, which had a level of 1650 ppb. The samples with gold included two that were collected from deep water (*see* above). Of 33 samples from CSS *Navicula* cruise 90035 that were analyzed, ten contained over 50 ppb Au in the mud fraction, including all five samples from Deer Cove. Six samples from Baie Verte also contained particulate gold (obtained by panning), including all five of the Deer Cove samples. Similar high gold levels were found in samples from Deer Cove collected during subsequent surveys. Deer Cove is a shallow shelf on the flank of Baie Verte that is exposed to high wave energy and iceberg impact. Bedrock depressions contain silty, postglacial mud overlain by a veneer of sand and gravel about 0.5 m thick. Preliminary sampling by C-CORE, following the initial results of this survey, suggested that there may be sufficient gold in the sand and gravel of Deer Cove to sustain cottage-scale mining.

Zone 5, the intertidal-supratidal zone, is generally narrow (a few tens of metres or less). The input of new sediment from coastal erosion and from rivers is negligible. However, zone 5 is relatively wide on the northeast coast — The Straight Shore — where the shallow gradient of the inner shelf, high exposure to waves, and the occurrence of Quaternary sediments have resulted in the formation of a variety of sandy, coastal landforms. A

cette zone quatre échantillons dans la baie Gander et cinq dans la baie Dog. Un échantillon de la baie Gander (92301-031B), extrait d'une profondeur d'eau de 2 m au large de l'anse Victoria, contenait une petite quantité d'or (teneur initiale de 44,9 ppb).

L'un des trois échantillons recueillis au large de La Scie pendant l'expédition 90035 contenait de l'or dans la fraction boueuse (échantillon 136, un sable graveleux provenant d'une profondeur d'eau de 83 m, 684 ppb). Il contenait en outre des particules d'or. Des sept échantillons prélevés au cours de l'expédition 91026 par le n.s.c. *Dawson*, six contenaient plus de 5 ppb d'or dans la fraction boueuse et deux d'entre eux avaient des teneurs relativement élevées (échantillon 026, sable recouvert de gravier, profondeur d'eau de 66 m, 109 ppb; échantillon 027, sable fin, profondeur d'eau de 77 m, 249 ppb). Les six renfermaient en outre des particules d'or. Deux échantillons récupérés au cours de l'expédition 92042 du n.s.c. *Parizeau* ont été analysés; ils ne contenaient que des traces d'or non visibles. Les sources de ces petites quantités d'or trouvées au large de La Scie étaient soit des sédiments glaciomarins préalablement vannés par les vagues et des quilles d'iceberg, soit un substratum rocheux minéralisé.

La baie Verte est la plus susceptible de receler des placers aurifères marins. La première découverte d'or a été faite dans des échantillons recueillis pendant l'expédition 90013 du n.s.c. *Hudson*. Parmi les onze échantillons analysés, sept contenaient de l'or détectable (> 5 ppb) dans un concentré de minéraux lourds, dont l'échantillon 90013-042, qui avait une teneur de 1 650 ppb. Des échantillons aurifères, deux provenaient d'une zone en eau profonde (voir ci-dessus). Des 33 échantillons de l'expédition 90035 du n.s.c. *Navicula* qui ont été analysés, dix contenaient plus de 50 ppb d'or dans la fraction boueuse, incluant les cinq échantillons prélevés dans l'anse Deer. Six échantillons de la baie Verte renfermaient également des particules d'or (obtenues à la batée), dont les cinq provenant de l'anse Deer. Des teneurs en or tout aussi élevées ont été obtenues d'échantillons de l'anse Deer prélevés au cours de levés subséquents. L'anse Deer est une plate-forme peu profonde sur le flanc de la baie Verte qui est exposé à des vagues de forte énergie et des impacts d'icebergs. Les dépressions dans le substratum rocheux sont remplies de boue silteuse postglaciaire recouverte d'un placage de sable et de gravier de quelque 0,5 m d'épaisseur. L'échantillonnage provisoire effectué par C-CORE suivant les résultats initiaux de ce levé laisse supposer que la teneur en or du sable et du gravier de l'anse Deer pourrait permettre une exploitation de petite taille.

La zone 5, zone intertidale-supratidale, est généralement étroite (quelques dizaines de mètres ou moins). L'apport sédimentaire actuel attribuable à l'érosion littorale et aux cours d'eau est négligeable. Toutefois, la zone 5 est relativement large sur la côte nord-est — The Straight Shore — où le faible gradient de la plate-forme continentale interne, l'action des vagues et la présence de sédiments quaternaires ont contribué

slow, long-term adjustment to rising sea level is occurring in this area so that, for example, the largest coastal sediment deposit, the Man Point dune foreland, has become destabilized (Shaw and Forbes, 1990a) and is undergoing rapid erosion, with sediment moving northwesterly in the narrow littoral-drift corridor, towards Hamilton Sound. Although the high wave energy is favourable for placer development, the lack of glacigenic sediments in the coastal zone and the absence of gold in those sediments where they do occur point to a low potential for the formation of gold placer deposits. No samples were assayed from the region with the most abundant intertidal and supratidal sediments — The Straight Shore —, but low gold levels in samples from the adjacent inner shelf (zone 4) suggest that gold levels would be low at the coast. In nearby Gander Bay, ten samples from zone 4 were analyzed and all had low gold contents; samples from Rodgers Cove had 5 ppb for a head grade. Similarly, all samples from Dog Bay had extremely low gold contents.

The zonation described above is difficult to apply to the long fiords that dissect the coast in this region and a separate model is therefore proposed, consisting of outer-, middle-, and inner-fiord environments. In the outer-fiord environment, relatively shallow bedrock sills have not been exposed in the surf zone because of limited postglacial sea-level lowering, so they are unlikely to have marine placers. The adjacent deep, muddy basin floors are also of no interest in this respect. Shallow areas are heavily impacted by icebergs, resulting in the formation of iceberg turbates. Although winnowing probably occurs, it is unlikely to produce marine placers. Postglacial mud occurs in banked deposits because of strong bottom currents; the glaciomarine deposits exposed on the adjacent seafloor date back to 11 ka and earlier and lie below a thin lag of fine, pebbly gravel. Although postglacial deposition is precluded because of the existence of currents, the glaciomarine muds have rarely been significantly eroded, so the enrichment of heavy-mineral populations by winnowing is limited.

Between the outer coast and the innermost parts of fiords, the coasts are rocky, with scattered gravel beaches. The fiord sidewalls are steep and have a thin veneer of sediment, with the thickest deposits, mostly glaciomarine mud, found in the deep, central part of the channel. With moderate to low wave energy, very little

à la formation de formes littorales sableuses de tous genres. Un lent ajustement à long terme à la montée du niveau marin a lieu dans cette région. C'est ainsi que le plus vaste dépôt de sédiments littoraux, le saillant de la pointe Man, s'est déstabilisé (Shaw et Forbes, 1990a) et qu'il subit une érosion rapide, les sédiments se déplaçant vers le nord-ouest dans l'étroit corridor de dérive littorale, en direction de la baie Hamilton. Même si la forte énergie des vagues est favorable à la mise en place de placers, l'absence de sédiments d'origine glaciaire dans la zone littorale et l'absence d'or dans ces sédiments, là où ils se trouvent, indiquent qu'il est peu probable qu'il s'y soit formé des placers aurifères. Aucun échantillon de la région où les sédiments intertidaux et supratidaux sont les plus abondants — le littoral dit The Straight Shore — n'a été titré; cependant, les faibles teneurs en or des échantillons provenant de la plate-forme continentale interne adjacente (zone 4) indiquent que les teneurs en or seraient faibles à la côte. Dix échantillons provenant de la zone 4 dans la baie Gander voisine ont été analysés et ont donné de faibles teneurs en or. Les échantillons de l'anse Rodgers avaient une teneur initiale de 5 ppb. Il en était de même de tous les échantillons de la baie Dog qui avaient des teneurs en or très faibles.

Les zones décrites ci-dessus sont difficiles à appliquer aux fjords profonds qui découpent la côte de cette région. Un modèle distinct est donc proposé; il comporte des milieux situés à l'entrée, au milieu et au fond des fjords. À l'entrée des fjords, des crêtes de substratum rocheux relativement peu profondes n'ont pas été exposées dans la zone de déferlement parce que la baisse postglaciaire du niveau marin a été limitée, ce qui porte à croire qu'il n'y a vraisemblablement pas de placers marins. Les planchers adjacents boueux profonds de bassins n'offrent également aucun intérêt à cet égard. Les zones peu profondes sont fortement perturbées par les icebergs, d'où la formation de sédiments perturbés par des icebergs. Même si le vannage s'y produit probablement, il n'a pas dû avoir contribué à la formation de placers marins. La boue postglaciaire forme des bancs sous la force des courants de fond; les dépôts glaciomarins exposés sur le fond océanique adjacent datent de 11 ka ou plus et sont recouverts d'un mince pavage de gravier caillouteux fin. Même s'il n'y a pas eu de sédimentation postglaciaire à cause des courants, les boues glaciomarines ont rarement été profondément érodées, d'où un enrichissement limité de populations de minéraux lourds par vannage.

Entre la côte externe et les portions les plus internes des fjords, les côtes sont rocheuses, ponctuées ici et là de plages de gravier. Les parois des fjords sont abruptes et sont recouvertes d'un mince placage de sédiments; les dépôts les plus épais, surtout des boues glaciomarines, se sont accumulés dans la partie centrale profonde du chenal. Cette région, où l'énergie

reworking, and no sources, this region has very low placer gold potential, despite the fact that enhanced levels of gold were found in this setting in inner Baie Verte.

In inner-fiord environments, wave energy is low and beaches have low crest heights and typically consist of either fine gravel or sand. The relative sea-level history has resulted in the formation of raised beaches and raised glaciomarine deltas, notably in Halls Bay and Green Bay. Deltas with coarse-grained deposits occur at the head of almost every fiord and have formed as a result of reworking of glacial sediments. Offshore, the water is relatively shallow and sediment is mostly glaciomarine, gravelly, sandy mud with a patchy veneer of postglacial mud or sandy mud. Creep terraces are common on steep fiord sidewalls. The low wave energy results in poor potential for marine placer development.

des vagues est moyenne à forte, le remaniement est très faible et les roches mères sont absentes, offre un potentiel aurifère très faible bien que l'on ait découvert des concentrations plus élevées dans un contexte semblable dans la portion interne de la baie Verte.

Dans les milieux situés à l'intérieur des fjords, l'énergie des vagues est faible, les crêtes de plage sont basses et les plages sont généralement composées de sable ou de gravier fin. Les fluctuations du niveau marin relatif ont créé des plages soulevées et des deltas glaciomarins soulevés, notamment dans la baie Halls et la baie Green. Les deltas de sédiments à grain grossier se rencontrent au fond de presque tous les fjords et se sont formés par suite du remaniement de sédiments glaciaires. Au large, l'eau est relativement peu profonde et les sédiments sont surtout composés de boue sableuse graveleuse d'origine glaciomarine, recouverte d'un placage de boue ou de boue sableuse postglaciaire. Les terrasses de reptation sont nombreuses sur les parois raides des fjords. La faible énergie des vagues n'est pas favorable à la mise en place de placers marins.

INTRODUCTION

Objectives and background

Under the auspices of the Canada–Newfoundland Co-operation Agreement on Mineral Development 1990–1993 (MDA 2), the Geological Survey of Canada initiated a project entitled 'Placer Mineral Potential off Northeast Newfoundland' (GSC Project 900032). The objectives were to map the distribution of surficial sediments and the abundance of placer minerals (particularly gold) off the northeast coast of Newfoundland and to develop local deposit models. The rationale for this effort was that the nearshore and inner continental shelf off northeast Newfoundland had been identified by the provincial government and other agencies (principally C-CORE — Centre for Cold Ocean Resources Engineering, Memorial University of Newfoundland) as having a higher potential for hosting placer gold than other parts of the Newfoundland inner shelf. There was a nearly complete absence of surficial geological information from inshore waters in the area. It was, therefore, hoped that, in addition to giving an initial evaluation of marine placer potential, a mapping project would provide essential baseline geological data. The purpose of this paper is to summarize the data that were collected during the MDA program, with an emphasis on the presence of gold in marine sediments.

Status of marine placer mining and exploration in Canada

Several factors were unfavourable to a search for marine placer deposits. There were concerns that local entrepreneurs (fishermen, tour operators, etc.) and others might object to mineral exploration and exploitation activities. An example of this kind of impediment was denial of permission for assessment of a potential marine gold-placer deposit in Nova Scotia because of objections by local (tourism) interests and a provincial government minister. An additional unfavourable factor was the lack of a legislative framework. In the 1980s, the former Department of Energy, Mines, and Resources prepared a draft Green Paper that outlined a *Canada Offshore Minerals Management Act*, but legislation was never enacted. Also, enthusiasm for marine placers was muted by the closure of nearshore gold-placer operations in Alaska, a region long known for high amounts of gold in beaches. These discouragements were offset somewhat by the hope that even very small placers could be worked as a cottage industry.

Assessments of the potential for several kinds of marine placer deposits have taken place in parts of eastern Canada in recent years. Emory-Moore et al. (1988) described potential chromium placer deposits — beach and nearshore sands — at Fox Island River in Port au Port Bay, western Newfoundland (their work was funded by the Canada–Newfoundland Co-operation Agreement on Mineral Development [1984-1989]). Hein et al. (1993) showed that in the Sept-Îles region of Quebec, glacio-isostatic rebound caused reworking of glacial and marine deposits to form modern placers. Heavy-mineral concentrations were up to 20 per cent in terrestrial glacial diamicton and 43 to 60 per cent in modern storm-berm and delta-top deposits. Twenty-seven million tonnes of titanium were believed to be available in modern terrestrial and seabed sediments. A third example is the study recently undertaken to evaluate placer gold potential on part of the inner Scotian

Shelf (Stea et al., 1993), funded under the Canada–Nova Scotia Co-operation Agreement on Mineral Development. The proposed model of placer formation was as follows: gold was eroded from lode-bearing bedrock highs during the last glaciation and an auriferous glacial diamicton was formed. This was reworked during the Holocene transgression and gold was redeposited in barrier systems. Interestingly, the sea-level histories of the last two examples contrasted: the Nova Scotia example is in a transgressive setting and the Quebec example is in a regressive setting.

Choice of study area

The document that most influenced the choice of a study area was a contract report prepared for the Newfoundland and Labrador Department of Mines and Energy by C-CORE. The objective of the C-CORE study (Solomon et al., 1989) was to conduct a regional assessment of the coastal and marine placer potential of Newfoundland. This was done by "...compiling and mapping data upon which the development of modern marine placers and the preservation of relict placers in the offshore depend." These data included coastal lode and placer mineral occurrences, onshore Quaternary geology, sea-level history, onshore drainage patterns, nearshore sedimentology, coastal exposure, and shelf gradient. The report described how these criteria could be used to assess the marine placer potential in terms of a source-conduit-sink framework.

Three factors were identified that control the processes of shelf sedimentation and, consequently, the formation of modern marine placers and the preservation potential of relict deposits. The first factor was sea level, which can change the position of the zone of sediment reworking by waves. With falling sea level, it was argued, downcutting rivers could supply sediment to the nearshore and offshore zones, where heavy minerals would be concentrated in beaches and shoals, forming allochthonous placers. Slow sea-level change would favour the development of autochthonous placers. The second factor was sediment supply. Four primary sources of sediment and heavy minerals to the offshore were identified: 1) modern fluvial discharge; 2) erosion of unlithified coastal bluffs; 3) erosion of coastal and submarine bedrock; and 4) submarine erosion and transport of unconsolidated sediment. The third factor was marine energy. Known, high-latitude, marine placers had formed preferentially in areas exposed to oceanic waves.

The report recommended the northeast and southwest coasts of Newfoundland as the areas most likely to host modern and relict marine placers. On the northeast coast, the area between Cape Freels and New World Island (zone 9) had a relatively high potential for medium-density mineral placers (chromium, zircon, and monazite) and some high-density minerals (gold, tungsten, and tin). Between New World Island and Ming's Bight (zone 10) there was a relatively high potential for high-density minerals, in particular gold. White Bay (zone 11) was considered among the regions most likely to have relict deposits, with gold and chromite being singled out. The Notre Dame Bay–White Bay region was identified as part of a larger region in which gold-bearing bedrock was subject to wave erosion and there was considerable potential for gold placers that could be mined by small operators.

REGIONAL SETTING

Relief and bathymetry

The Northeast Newfoundland Shelf as defined by Warren (1976) lies north of latitude 50°30′N, but on Chart 802A (Canadian Hydrographic Service, 1990), it is depicted as lying east of Fogo Island. Here we define it as the region lying off the northeast Newfoundland coast between White Bay and the west side of Bonavista Bay (Fig. 2) and extending seaward to the shelf break at a depth of about 400 m (about 230 km offshore from Cape Freels). The morphology of the shelf is complex and includes outer-shelf banks and transverse channels (Warren, 1976). In the study area, the principal feature of the shelf is the northeast-trending Notre Dame Channel, which is mostly deeper than 300 m and has a maximum depth of 406 m and a sill at a depth of 320 m (Fig. 3). A second basin just east of the Horse Islands extends to a depth of 329 m. The coastal fringe shallower than 200 m is extensive in two areas only, off the north and northeast coasts of Baie Verte Peninsula and in the Fogo Island–Cape Freels region. In the latter region, the 100 m isobath extends offshore an average of 25 km, forming the largest area of shallow water in the study area.

The most striking aspect of the inner shelf is the series of north- to northeast-trending, glacially overdeepened, coastal basins (Fig. 3), the largest of which is White Bay, a funnel-shaped embayment that has a maximum depth of 536 m and a sill (just north of the Horse Islands) at a depth of about 280 m. Baie Verte is a minor embayment with a maximum depth of 324 m and a sill at a depth of 192 m. The Green Bay basin is an elongate trough with a maximum depth of 411 m and a sill depth of about 280 m. Halls Bay is even more elongate and reaches its maximum depth of 490 m just south of a sill at a depth of 250 m near Little Bay Island; another basin that extends north has a maximum depth of 370 m and a sill at about 290 m. Continuing east, other basins are as follows: a basin east of Long Island (maximum depth 536 m, sill depth 290 m), Badger Bay (maximum depth 525 m, sill depth 290 m), and New Bay (maximum depth 439 m, sill depth about 200 m). The Bay of Exploits contains two deep troughs. At the head of the western trough is an extensive shallow area, seaward of which are several relatively shallow basins separated by sills; beyond these lies the deepest basin in the whole region, with a maximum depth of about 673 m and a sill depth of approximately 210 m. The eastern basin of Bay of

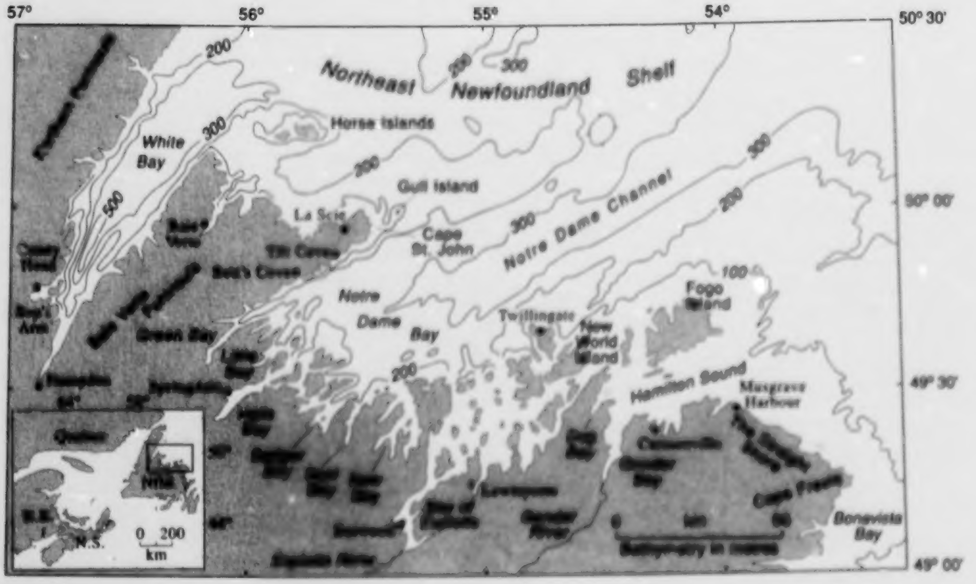
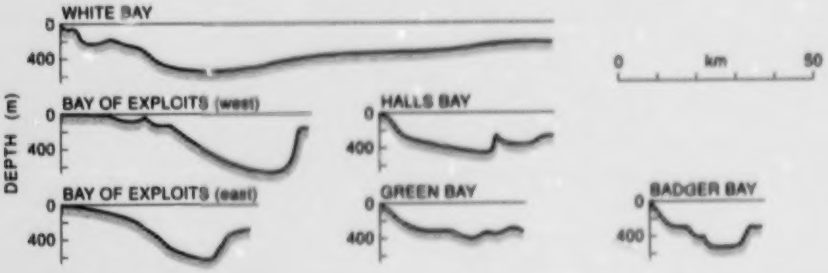
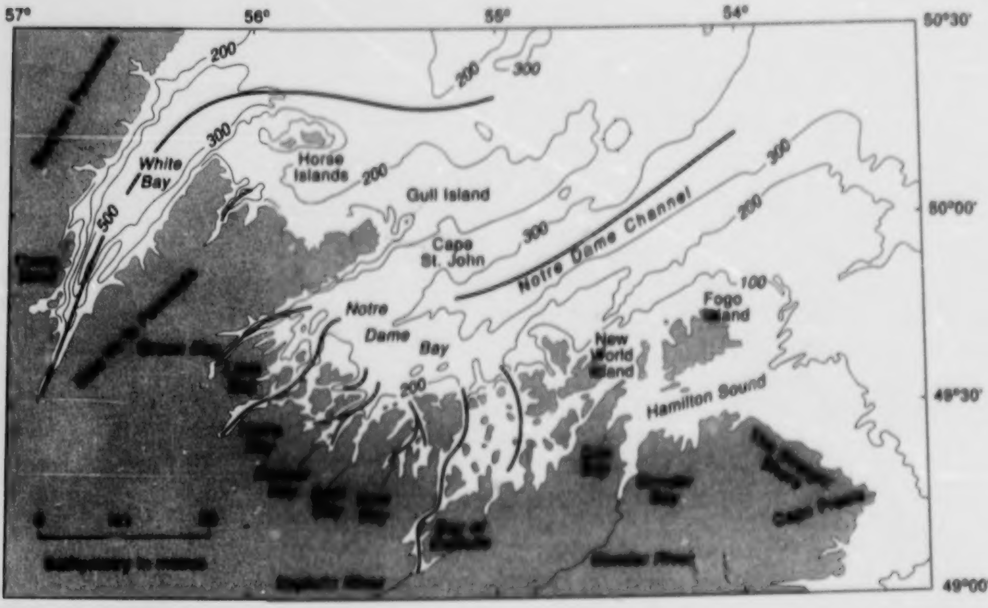


Figure 2. Map of the study area showing simplified bathymetry. Many isobaths have been omitted from the complex fiord coast between Twillingate and Green Bay.





Exploits is shorter, slightly shallower (maximum depth 604 m), and has a sill at a depth of 250–300 m. East of Bay of Exploits, the major coastal troughs are absent, but shallow (<100 m), silled basins are common.

Geology

Onshore, the study area contains elements of three of the four tectonic zones of Newfoundland (Colman-Sadd et al., 1990). The Humber Zone lies west of the Baie Verte–Brompton Line and contains a basement of continental crust, metamorphosed and intruded during the Middle Proterozoic; it includes Late Proterozoic to Middle Ordovician cover rocks. The Dunnage Zone, east of the Humber Zone, is characterized by Cambrian to Middle Ordovician, submarine, volcanic rocks and early Ordovician ophiolite suites, and is divisible into two subzones. In the Notre Dame Subzone (west of New Bay), extrusive and intrusive igneous rocks are overlain by nonmarine Silurian rocks, whereas in the Exploits Subzone (east of New Bay), Middle to Late Ordovician shales predominate. The Gander Zone lies east of the the Grub Line (which intersects the coast just east of Carmanville, Hamilton Sound) and contains quartz-rich, siliciclastic, sedimentary rocks of probable Cambrian and Ordovician age, although in coastal areas of the study region, Devonian and Carboniferous granite intrusions predominate.

The zone boundaries, deep crustal block boundaries (*see* Colman-Sadd et al., 1990), and faults trend northeast, imposing a strong structural grain that is reflected in the orientation of valleys and coastal embayments. This structural grain is also imparted to the bedrock geology of the offshore area (Fader et al., 1989), so that, for example, major faults are oriented northeast. A pair of faults just off the east and west coasts of White Bay bound a downfaulted block of lower Carboniferous rocks (mainly carbonate rocks); the same rocks also lie offshore from Baie Verte Peninsula, except its northwest part, where upper Proterozoic rocks occur at the seabed. A major fault off the east coast of Baie Verte Peninsula coincides with the boundary of the relatively shallow (<200 m) inner shelf in that region. Between this fault and another on its south side, the Notre Dame Channel is floored for the most part by Cambrian–Ordovician rocks, with smaller areas of Carboniferous rocks. Carboniferous rocks predominate north of latitude 50°N. A band of Silurian–Devonian rocks runs through Fogo Island; to the east is a narrower band of middle-upper Ordovician rocks. The shallow (<200 m), inner shelf east of Hamilton Sound, offshore from The Straight Shore, is floored by Devonian granite; upper Cretaceous–Tertiary rocks occur farther offshore (Fig. 4).

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Figure 3.

Locations of the principal, ice-deepened troughs on the inner shelf in the study area, with simplified bathymetric profiles for selected coastal examples, based on data from Canadian Hydrographic Service (1988a, b, c, 1990).

Gold mineralization

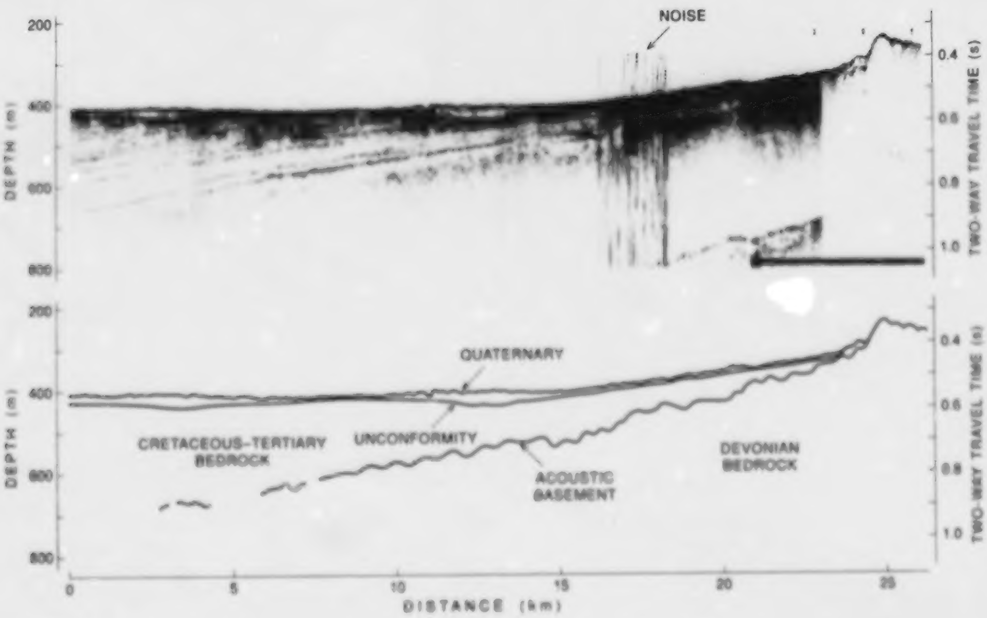
These notes on gold mineralization onshore in the study area are based on the summary by Emory-Moore (1991, p. 10–13). Gold has been recovered at a number of sites (Fig. 5) and is the target of continued exploration activity. Two styles of mineralization occur: volcanogenic massive sulphide mineralization with which gold is often associated, and epigenetic vein and epithermal deposits in which gold is the primary target.

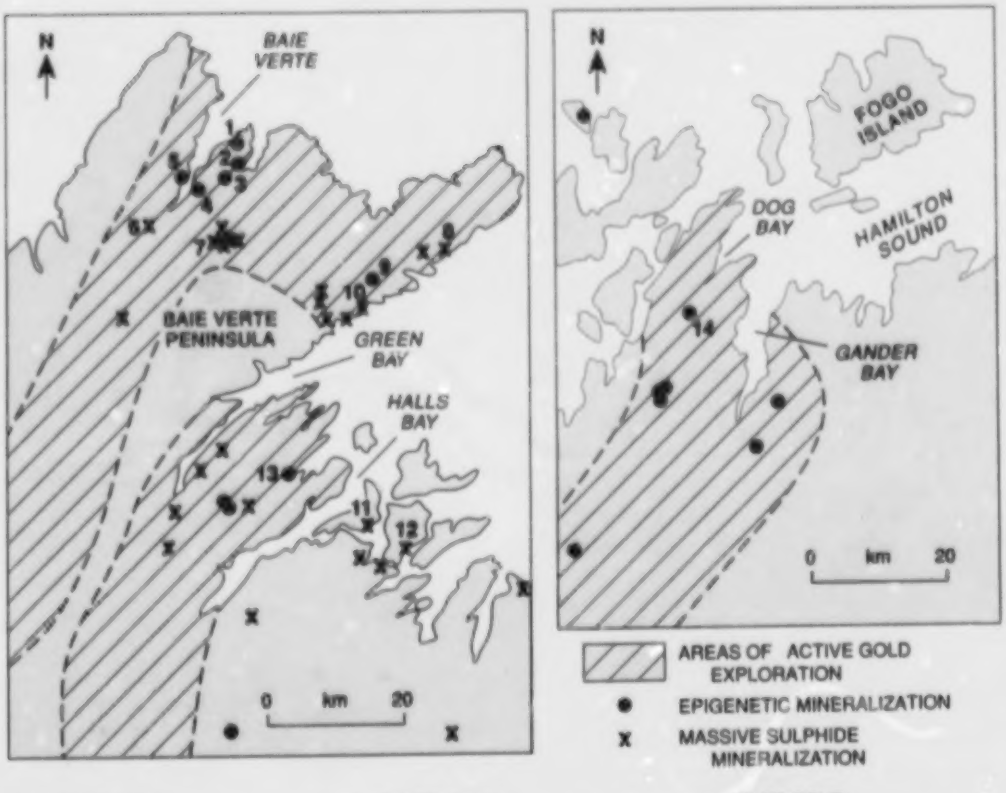
In general, gold content is low in massive sulphide deposits in the study area and the gold is very fine grained. Most of the volcanogenic massive sulphide deposits on Baie Verte Peninsula are in ophiolitic sequences. They include the Tilt Cove, Betts Cove, Consolidated Rambler, and Terra Nova deposits. Gold was a smelting byproduct at the Consolidated Rambler mine. In the Halls Bay area, sulphide deposits in the Lushes Bight Group ophiolites contain pyrite, chalcopyrite, pyrrhotite, magnetite, and sphalerite with local, minor concentrations of gold and silver. Gold has been recovered from the Little Bay and Miles Cove deposits. The volcanic rocks on Pilley's Island host sulphide deposits without gold. In her discussion of massive sulphide deposits in the study area, Emory-Moore (1991) concluded that the gold content of these deposits seemed quite low and the gold, very fine grained.

Epigenetic gold is found in veins associated with major north-northeast- and northeast-trending faults and lineaments. Significant epigenetic deposits on Baie Verte Peninsula occur at Nugget Pond, Goldenville, Pine Cove, Stog'er Tight, and Deer Cove. The gold commonly occurs as free, fine-grained (<0.05 mm) particles. At Nugget Pond, gold grains range in size from 0.01 to 0.1 mm and contain silver. Several occurrences are in the northeastern Dunnage Zone (Evans, 1991), near Gander Bay and Dog Bay.

Coastal geomorphology

The shores of the study area are predominantly bedrock, with very limited development of depositional landforms, in part reflecting a restricted sediment supply to the modern coast. Beaches occupy only 16 per cent of the total shoreline. Exposures of unconsolidated sediments in backshore cliffs are extremely rare and are restricted primarily to inner-fiord locations in Notre Dame Bay. The degree of wave exposure is low in very protected, inner-bay settings and high on extensive stretches of outer coast that are fully exposed to the Labrador Sea and North Atlantic Ocean.





1 DEER COVE
2 GOLDENVILLE MINE SITE
3 STOG'ER TIGHT
4 PINE COVE
5 BAIE VISTA
6 TERRA NOVA
7 CONSOLIDATED RAMBLER
8 TILT COVE
9 NUGGET POND
10 BETTS COVE
11 MILES COVE
12 PILLEYS ISLAND MINE SITE
13 LITTLE BAY MINE SITE
14 CLUTHA

Figure 4.

Airgun profile across the Northeast Newfoundland Shelf illustrating the contrasting acoustic character of differing bedrock lithological units. A veneer of Quaternary sediments covers well bedded, seaward-dipping, coastal-plain type, Upper Cretaceous–Tertiary sedimentary rocks (siltstone, sandstone, shale, and mudstone), which overlie Lower Paleozoic rocks of the Appalachian Orogen (Devonian granite) that have a dense, acoustically incoherent tone on seismic records. Cruise 91026, day/time 188/05:17–08:15. This profile extends east-northeast and begins at a point east of the Penguin Islands (The Straight Shore), just outside the area covered by Figures 1 and 6.

The northeast coast from Musgrave Harbour to Cape Freels is characterized by numerous sandy beaches and the most extensive areas of coastal dunes on the island, apart from the southwest coast (Forbes, 1984). The morphology of coastal environments strongly reflects the waning of the Holocene transgression about 3000 years ago (Shaw and Forbes, 1990a). The dune-ridge foreland at Man Point, just south of Musgrave Harbour, is mantled by up to 3 m of freshwater peat that began to form about 3.2 ka. Moribund flood deltas, flood channels, and overwash fans at Deadman's Bay are evidence of an arrested transgressive phase and date to earlier than 1.8 ka. Coastal dunes at Cape Freels contain an extensive peat horizon that dates to 1.6 ka and is evidence of a period of dune stability at that time.

Climate

Climate is controlled by proximity to the Canadian mainland and to the frigid water of the Labrador Current. Most of the region falls within the East Coast and Hinterlands climatic zone (Banfield, 1981), characterized by 1100–1500 mm of precipitation, 65–75 per cent of which falls as snow, and cold winters, with continuous snow cover until March. Spring is cool and late, with sea ice persisting typically until mid-May (occasionally later: *see* below), and summers are warm and sunny. At Twillingate, the mean maxima and minima are -1.3°C and -6.8°C in January and 19.9°C and 11.6°C in July. The heads of Bay of Exploits, Halls Bay, Green Bay, and White Bay, together with the southern part of Baie Verte Peninsula, fall within the Central Lowlands climatic zone (Banfield, 1981), which is characterized by greater continentality. Annual precipitation is nearly 1200 mm and winters are colder and drier than the first zone, with occasional minima in the -25°C to -30°C range. At the coastal settlement of Springdale, the mean maxima (minima) in January and July, respectively, are -1.7°C (-11.0°C) and 22.4°C (10.9°C). This is the least windy area of the island (Banfield, 1981). Predominant winds at Twillingate are from between the south and west. The average number of days with fog is low in this region relative to other parts of the island of Newfoundland: only 42 at Twillingate and 19 at Botwood, compared with 155 at Cape Race, the foggiest place on the island.

Figure 5.

Onshore gold occurrences and deposits in the study area (after *Emory-Moore, 1991, Fig. 2).*

Currents, tides, and waves

The cold Labrador Current is the dominant feature of circulation on the shelf off eastern Newfoundland. It consists of water at temperatures between 3.0°C and -1.5°C and salinities ranging from 32.0 ‰ to 34.5 ‰ (Farmer, 1981). General flow is to the east and southeast on the Northeast Newfoundland Shelf, with near-surface speeds of $0.3\ m\cdot s^{-1}$ (Petrie and Anderson, 1983), although this cold water is probably warmed and diluted near the coast (Steele, 1983). The range of mean tides varies from 0.8 to 1.0 m, with an average of 0.9 m (Canadian Hydrographic Service, 1995); for large tides, the range varies from 1.2 to 1.7 m and the average range is 1.4 m. Sea level exhibits a quasi-periodic variation probably caused by density changes in the Labrador Current. Thus, at St. John's, sea level starts to rise in May and peaks in October, resulting in an annual fluctuation of 0.14 m (Petrie and Anderson, 1983).

The Northeast Newfoundland Shelf is exposed to waves from the northwest (in part), north, northeast, and east. Neu (1976) published an exceedance diagram for one year (1970) of wave data in a 5° by 5° area north of Notre Dame Bay. A significant wave height of 2 m was exceeded 50 per cent of the time and a height of 3 m, about 20 per cent of the time. Studies by Neu (1976, 1982) and Walker (1976, 1984) show that wave energy is lowest in the summer months and rises from October onward to peak in December. The highly irregular nature of the coast leads to great variation in exposure to waves, so that the outer headlands and coasts are highly exposed, whereas the fiords and island archipelagos are sheltered.

Ruffman et al. (1991) compiled articles from the *Western Star* (published in Corner Brook) that describe severe storms in Newfoundland. These articles show how susceptible the outer coasts of the study region are to storm waves. Reports frequently cite damage at La Scie, Tilt Cove, and Horse Islands, among other places. The Straight Shore, the coast from Cape Freels to Hamilton Sound, is often mentioned in reports of storm damage. For example, a report (Ruffman et al., 1991, p. 400) dated 28 November 1947 states the following:

> News comes from Cape Island (Cape Freels) that the tremendous heavy seas whipped up by recent N.E. gales completely inundated the narrow neck of the land which joins the settlement to the mainland, cutting a channel approximately 150 feet wide and several feet deep.

Sea ice and icebergs

Markham (1980) analyzed data for 1963–1973. He showed that the mean sea-ice edge typically spread south in January and reached White Bay and western Notre Dame Bay by the end of the month. At that time, ice between Botwood and Hamilton Inlet had formed locally and was thin. The southern limit of sea ice reached Cape Freels by mid-February. By April, melting at the ice edge began to outweigh southward drift and the pack began to retreat, reaching Cape Freels by the second week and Cape Fogo by the third. Ice had commonly disappeared completely from the study area by July 2. However, on 4 July 1991, CSS *Dawson* had to abandon survey lines just northeast of Baie Verte Peninsula due to heavy pack ice.

Icebergs originating in west Greenland and, to a lesser extent, in the eastern Canadian Arctic drift in the Labrador Current and ground in shallow water along the north and east coasts of Newfoundland. The drafts of larger icebergs off eastern Canada and Greenland are commonly in the range of 200 to 400 m. These icebergs cause moderate to intense disturbance on the Labrador Shelf and the northern Grand Banks of Newfoundland. Unfortunately, no disturbance data existed for the Northeast Newfoundland Shelf.

Many icebergs were encountered during surveys in 1991. For example, a grounded iceberg was observed in 91 m of water off Tilt Cove on 2 July. Many grounded icebergs were seen at Gull Island on 3 July and a large number of grounded icebergs were noted off The Straight Shore a few days later. Icebergs were still present in August: a grounded iceberg was observed off Spear Point (White Bay) on 11 August and another near Moreton's Harbour a few days later.

Settlement

Under the Treaty of Utrecht (1713), fishing rights in this region were ceded to France. Few English-speaking settlers lived here at that time, but as the eighteenth century progressed, Newfoundland fishermen extended their activities into Notre Dame Bay. They settled at Twillingate and on Fogo and Exploits islands (Rowe, 1980). According to the terms of the Treaty of Versailles (1783), the boundary of the 'French Shore' was shifted westward from Cape Bonavista to Cape St. John and Newfoundland settlers were given undisputed sway over The Straight Shore and Notre Dame Bay. The salmon and seal fisheries had attained importance by that time (Rowe, 1980). The French gave up their rights to the area west of Cape St. John in 1904. The legacy of their fishing activities in the region remains in the names of settlements such as Fleur de Lys, Baie Verte, La Scie, and Twillingate (a corruption of Toulinguet).

Notre Dame Bay, particularly the Exploits region, was the last haunt of the native Newfoundlanders, the Beothuks. Lieutenant David Buchan led an expedition to Bay of Exploits in 1811 in an attempt to make contact with them, and William Epps Cormack attempted to do likewise in 1822, but the Beothuks eventually disappeared through a series of misfortunes, including murder and disease. The last of the race, a woman named Shanawdithit, died in 1829.

The study region lies north of the Trans-Canada Highway, to which the coastal settlements are linked by a series of branch roads. Jackson's Arm and Sop's Arm are fishing settlements and Hampden is a centre for logging operations. Baie Verte Peninsula has a number of small fishing ports, for example La Scie, as well as a history of mining. Newfoundland's first mine, the Tilt Cove copper mine (now abandoned), was established there in 1864. The largest settlement, Baie Verte, was the site of a large asbestos mine, now also closed. Other major centres in the region are Springdale, Botwood (a shipping point for pulp and paper products from the Bishop's Falls–Grand Falls region), Lewisporte, and Fogo. Twillingate was formerly the highly prosperous centre for sealing in eastern Newfoundland. Numerous smaller settlements are fishing centres, for example Carmanville and Musgrave Harbour. The New World Island region, linked to the mainland by causeways, has a large number of small communities.

METHODS AND DATA SET

Existing data

Part of the rationale for the present work was the lack of marine geological data in this region. The principal source of information was geophysical and core data collected during CSS *Hudson* surveys 75009 and 78023 (Haworth, 1975, 1978) and summarized by Dale and Haworth (1979), who mapped the distribution of five seismic facies on the Northeast Newfoundland Shelf: bedrock (unit 5), glacial diamicton (unit 4), a semistratified unit (unit 3), a stratified unit (unit 2), and an acoustically transparent unit (unit 1). Their core 006, one of 11 piston cores collected during cruise 78023, penetrated units 4, 2, and 1. It was designated 78023-20 in papers by Mudie and Guilbault (1982) and Scott et al. (1984, 1989), who interpreted lithological, paleomagnetic, foraminiferal, dinoflagellate, pollen, isotopic, and radiocarbon data.

Miller et al. (1995) and Miller (1998) summarize postglacial climate change and paleoceanography of the Northeast Newfoundland Shelf on the basis of data from both onshore and offshore. They argue that glacial conditions existed on the inner shelf from 15 ka to 13 ka and distal glaciomarine conditions, from 13 ka to 10 ka. Deglaciation commenced on the north coast at about 13 ka.

Slatt (1975) and Slatt and Gardiner (1976) published data based on petrological and geochemical analyses of grab samples from Halls Bay. Among their conclusions were 1) that fiord sediments were of local origin, 2) that some sediment had been transported into the fiord by ice rafting, and 3) that anomalous copper concentrations in coarse silt in the bay were due to dispersion of copper from sources along the west coast of the bay.

The onshore data may be subdivided into two types. The first is a large body of data relating to Quaternary sediments in coastal areas, including papers by early workers (*see* review by Tucker, 1976) and by various investigators working for the Newfoundland Department of Mines and Energy. The second is a small body of work on coastal geomorphology, principally a review of Newfoundland coastal environments by Forbes (1984) and a paper dealing with the evolution of coastal landforms on The Straight Shore (Shaw and Forbes, 1990a).

Logistics

A 20 m wooden survey vessel, CSS *Navicula*, was used for most of the surveys in coastal waters. It generally operates day trips from a harbour within several hours steam from the chosen survey area. Because of this, it proved impractical for surveys in some parts of the study area. Sop's Arm was used as a base for surveying inner White Bay, Baie Verte was ideally placed for surveys of Baie Verte and Ming's Bight, and La Scie was used as a base for operations off northern Baie Verte Peninsula; however, the east coast of Baie Verte Peninsula was too distant from a suitable harbour. The area accessible from Springdale extended from Little Bay in the west to Long Island in the east. Using Twillingate as a base, CSS *Navicula* surveyed areas as far southwest as the entrance to Bay of Exploits. Carmanville was a base for operations in Hamilton Sound.

The larger survey vessels, CSS *Hudson*, CSS *Parizeau*, and CSS *Dawson*, operated from either Dartmouth, in Nova Scotia, or St. John's and Lewisporte, in Newfoundland. They were used to survey areas in which it was considered impractical to operate the *Navicula*. However, they could not enter confined coastal areas after dark; consequently, large areas of relatively deep, offshore waters were explored at night. The coastal waters surveyed from the larger vessels included the east coast of Baie Verte Peninsula, Green Bay, Wild Bight, Badger Bay, New Bay, Bay of Exploits, and the areas off Fogo Island and The Straight Shore.

Surveys

Six surveys were completed along the northeast Newfoundland coast over a three-year period. Ships' tracks and sample locations are shown in Figure 6 (in pocket). Survey particulars, namely ships' tracks, sample descriptions and locations, acoustic data, etc., are given in a series of GSC Open File reports (except for the report on CSS *Parizeau* survey 92042, which was not published). CSS *Hudson* survey 90013 was completed in June 1990 within an area extending from White Bay to Hamilton Sound. The objectives were to collect regional, high-resolution, seismic reflection data to provide insight into the nature and distribution of Quaternary sediments in the region, and to obtain reconnaissance core and grab samples for gold assay and geochemical analyses. These data complemented previous work carried out farther offshore (Haworth, 1975, 1978; Dale and Haworth, 1979) and provided a framework for future cruises. CSS *Navicula* cruise 90035, completed in August 1990, was designed to provide more complete survey coverage in those areas previously visited by CSS *Hudson*. Detailed surveys were carried out in Baie Verte, off La Scie, Halls Bay, and Hamilton Sound.

The third survey in the series, CSS *Dawson* 91026, was designed to further assess the potential of the northeast coast to host marine gold placers and to provide more information on the nature and extent of Quaternary sediments. Regional tracks extend from Cape Freels west to La Scie, with more detailed tracks in the Bay of Exploits, Tilt Cove, Betts Cove, Hamilton Sound, and the Funk Island region. This cruise was followed by CSS *Navicula* survey 91031 in August 1991. The objectives were to obtain sidescan-sonar coverage in areas believed to have a high potential for marine placers and to collect acoustic and sample data from unsurveyed inlets and adjacent inner shelves. Surveys were conducted in Baie Verte, Ming's Bight, White Bay, Moreton's Harbour, along the west side of New World Island, and in Twillingate Harbour.

In June 1992, a nearshore and beach survey program, cruise 92301, was carried out to access coastal waters shallower than 20 m using the charter vessel MV *Nicholas and Paul*, a Boston whaler, and a 5 m inflatable Zodiac. The objectives of this survey were to collect sample data from the beach and coastal waters proximal to onshore vein-deposit gold occurrences and to map the distribution and extent of coastal sand bodies. Surveys were run in Dog and Gander bays, in Green Bay, and in Baie Verte. Deer Cove was also revisited to obtain detailed sidescan coverage and grab samples in water depths of less than 6 m and to collect sediment samples from the beach.

The final cruise, CSS *Parizeau* 92042, was completed in October 1992. Its objectives were to survey and sample off the east coast of Fogo Island and in Badger Bay, New Bay, Wild Bight, and Green Bay. Deer Cove and the La Scie area were revisited to collect vibracores, and piston cores were obtained in Badger Bay and New Bay.

Survey technology

Survey methods varied depending on the vessel size, the location of the survey, and the specific objectives. Surveys CSS *Hudson* 90013, CSS *Dawson* 91026, and CSS *Parizeau* 92042 were designed to provide regional, deep-water coverage off the northeast Newfoundland coast and to overlap areas surveyed previously by Dale and Haworth (1979). In order to resolve acoustic units and to measure Quaternary sediment thickness, seismic reflection data were obtained using the Huntec DTS (deep-towed boomer) system, air guns and sleeve guns, and 12 kHz and 3.5 kHz sub-bottom profilers. The lithology of acoustic units was determined by piston coring and vibracoring (the latter generally in shallow areas with hard bottoms). Sidescan sonograms were collected to complement seismic data (mostly in water depths shallower than 100 m) and, where possible, these data were groundtruthed with seabed grab samples and photographs.

CSS *Navicula* surveys 90035 and 91031 provided more extensive coverage of shallow, easily accessible parts of the inner shelf and overlapped the regional tracks offshore from Baie Verte and Notre Dame Bay. Data were collected in order to map the nature and distribution of Quaternary sediment in less than 150 m of water with emphasis on the stratigraphy and seabed depositional environments in less than 50 m of water, where economic placer extraction would be feasible. In addition to bathymetry, acoustic data were collected using the following systems: Seistec (a high-resolution, seismic reflection system useful for resolving internal reflections in muddy sediments in shallow water); a Datasonics bubble pulser (good penetration to bedrock in most cases); and a Klein 595 sidescan sonar system. Acoustic data were groundtruthed with grab samples, seabed photographs, and, in the case of survey 90035, Alpine gravity cores.

Shoreface and beach surveys were conducted during cruise 92301 to provide continuous data coverage from the beach outward to previously surveyed coastal waters in Baie Verte, Green Bay, Gander Bay, and Dog Bay, and to sample in water depths less than 10 m. Beach samples were collected by hand and beach profiles were measured with a Geodimeter 140H infrared electronic survey instrument and Emery poles. Klein 401 sidescan sonar surveys were run from the Boston whaler and echo-sounder data were collected from the Zodiac. These data were verified using seabed grab samples. In deeper water (generally more than 10 m), sidescan-sonar, Datasonics bubble pulser, and 3.5 kHz records, together with grab samples and seabed photographs, were collected from the *Nicholas and Paul*.

Sampling methods

Core collection

Four types of corers were used throughout the three-year program: the Atlantic Geoscience Centre (AGC) Long Core Facility piston corer, the AGC Benthos piston corer, the Alpine gravity corer, and the vibracorer. The AGC long corer was used on cruise 90013 at five coring locations in water depths exceeding 240 m. It is the largest of the four corers, housing a minimum of three and a maximum of ten 3 m long core barrels with an inside diameter of 11 cm. The Benthos piston corer is smaller than the AGC long corer and was used in water depths exceeding 75 m on cruises 91026 and 92042. The core barrel has a length ranging from 3 to 18 m and an inside diameter of 7 cm. All three attempts were successful during cruise 91026 in the Bay of Exploits in water depths from 77 to 207 m. Three attempts on cruise 92042, in water depths of 196 to 262 m in Badger and New bays, were also successful.

The Alpine gravity corer was used successfully aboard cruise 90035 (CSS *Navicula*), collecting seven cores at nine stations. The barrel was 3 m long and its internal diameter was 12 cm. The vibracorer was fabricated by Brooke Ocean Technology for penetrating sandy sediments and was used on cruises 91026 (CSS *Dawson*) and 92042 (CSS *Parizeau*). The frame is 6 m high and self supported, with a 3 m or 6 m long core barrel. During cruise 91026, three attempts were made to core in the study area in water depths from 55 to 83 m and two attempts were successful. Vibracoring was attempted at ten locations on cruise 92042 in water depths from 34 to 91 m; however, cores were collected at only five sites. Stiff, fine, silty sand at several of these sites prevented proper penetration; at the last site, the frame support was severed from the upright barrel housing on the bottom during recovery.

Seabed and beach samples

Seabed samples were collected using four types of grab samplers. Large- and medium-sized IKU grab samplers were deployed from the gallows aboard CSS *Dawson*, CSS *Hudson*, and CSS *Parizeau*. They penetrated the surficial gravel lag to a depth of approximately 0.3 to 0.5 m and collected sediment volumes of 0.38 m^3 (large size) and 0.25 m^3 (medium size). The van Veen grab sampler was hydraulically operated from booms aboard the larger vessels as well as the CSS *Navicula* and MV *Nicholas and Paul*. It worked most efficiently in sand and pebbly sand, penetrating the top 0.10 to 0.15 m of the seabed and collecting 0.01 m^3 of sediment. Coarser surficial lags would frequently jam the teeth of the sampler and the finer fraction of the sample would be lost during recovery. The Ponar sampler was hydraulically operated from the boom aboard the MV *Nicholas and Paul* and was lowered by hand and retrieved from the Boston whaler and Zodiac inflatable. It penetrated the top 0.1 m of the seabed, collecting 0.002 m^3 of sediment. The Ekman sampler was lowered by hand over the side of the Zodiac and was only suitable in sandy environments devoid of a gravel lag surface. It penetrated the top 0.1 m of the seabed, collecting about 0.01 m^3 of material. Beach samples were collected using a hand-held scoop. The sample was taken from the surface to a depth of 0.15 m and included all grain sizes within the profile. A standard 0.003 m^3 of beach material was collected at each site and stored in labelled, doubled, plastic bags.

Adjustment of sample depths

Because ship sounders are positioned at varied depths below water level, sounder readings in the cruise reports for cores, grab samples, and bottom photographs have been increased by the following amounts: 5 m for CSS *Hudson*, CSS *Dawson*, and CSS *Parizeau*, 3 m for CSS *Navicula*, and 1 m for MV *Nicholas and Paul*. These values, which appear in the text and also in Appendix 1, are better approximations of true depth than those cited in the cruise reports; they have not been adjusted to include tidal effects.

Sample analysis and reporting of assay results

Analyses were completed for selected samples from all cruises. The various analytical methods used are described below. Appendix 1 provides information on sample location, description, depth, sampling method, and gold concentration (ppb).

Cruise 90013 (CSS *Hudson*)

Twenty-nine samples were analyzed from cruise 90013. Approximately 0.011 m^3 of each van Veen sample and 0.046 m^3 of each IKU sample were sieved to pass through a mesh size of <2 mm, then panned to obtain 60 g of heavy-mineral concentrate (Emory-Moore, 1991). A 30 g subsample of the heavy-mineral concentrate was analyzed for gold by fire assay. Small, unsieved subsamples were also assayed for gold using fire assay and analyzed for major and trace elements using lithium borohydrate fusion followed by inductively-coupled plasma mass spectroscopy (ICP-MS). Results are reported in GSC Open File 2294 (Shaw et al., 1991).

Cruise 90035 (CSS *Navicula*)

Subsamples of 86 samples were wet sieved through a 0.063 mm mesh. Fractions over 0.063 mm were dry sieved through a bank of sieves with mesh sizes ranging from 0.105 mm to 76.2 mm. The sand fraction of each sample was weighed and panned to a concentrate of 23 to 25 g. The concentrate was further panned to a sample containing 50 to 150 grains. Gold grains were picked and mounted for grain morphology examination under the scanning electron microscope and grain chemistry evaluation using energy-dispersive X-ray analysis. In addition, the mud fractions of each sample and five blind duplicate samples were analyzed for gold and trace elements using neutron activation analysis (NAA). A 30 g, unsieved subsample of each original sample was analyzed for major and trace elements using lithium borohydrate fusion followed by ICP-MS. Results were reported in GSC Open File 2415 (Emory-Moore, 1991).

Cruises 91026 (CSS *Dawson*) and 91031 (CSS *Navicula*)

Seventy-four samples were analyzed from these cruises (Emory-Moore and Davis, 1992). The percentage by weight of gravel ($D \geq 2$ mm), sand ($0.063 \leq D < 2$ mm), and mud ($D < 0.063$ mm) was determined using wet-sieving techniques on a 5 kg split of each sample. A small split of each sample was archived for future reference. A 30 g subsample of the sand fraction and a 30 g subsample of the mud fraction of each of the sieved, 5 kg samples were analyzed for gold and trace elements by NAA. Duplicate splits of seven of the gold-bearing samples were re-analyzed to evaluate analytical precision and repeatability.

A third split of each sample was weighed and panned to a concentrate of 23 to 25 g. The concentrate was further panned to a sample of 50 to 150 grains. Gold grains were picked and mounted for examination under the scanning electron microscope. The dry weight of the total panned sample was estimated by subtracting the moisture content of each sample from the total wet weight of the sample. Results are reported in GSC Open File 2591 (Emory-Moore and Davis, 1992).

Cruises 92301 (MV *Nicholas and Paul*, small boats, and beach sampling) and 92042 (CSS *Parizeau*)

Fifty-nine samples from both surveys, weighing approximately 5 kg each, were classified by wet screening into six size fractions ranging from $D < 0.075$ mm to $D > 1.68$ mm (M. Kuryluk and C.D. Raymond, unpub. rept., 1993; Edwardson et al., 1993a). The fraction larger than 1.68 mm was dried, weighed, and stored. A pipette analysis was performed on the fraction under 0.075 mm for weight determination and subsampled for gold assay. The four intermediate-sized fractions were individually concentrated using the Kuryluk mineral separator to produce a separate concentrate (specific gravity >3.5) and float from each size fraction. The float material was dried and stored. The concentrate was examined with a binocular microscope to determine gold-grain content and shape. Each concentrate was dried and weighed and individual gold grains were isolated and photographed using the microprobe. The gold grains were then digested in aqua regia and the gold, silver, and copper content of the grains was determined by atomic absorption. The remaining concentrate for each sample was combined for gold determination by fire assay with an atomic absorption finish. Gold values (ppb) were calculated from the assay values obtained on the concentrate, the subsamples over 0.075 mm, and isolated gold grains. Results are given in GSC Open File 2772 (Edwardson et al., 1993a).

Detailed grain-size analyses were completed in-house on an additional 72 samples selected from the six surveys to supplement previous grain-size data and to provide a more complete grain-size suite for a range of depositional environments. Granule and gravel fractions (D > 1 mm) were sieved. The sand fraction was analyzed using a settling tube and the mud fraction, using a Sedigraph™ instrument.

QUATERNARY STRATIGRAPHY OF THE INNER SHELF

Seismostratigraphic units

Seismostratigraphic units are defined as successive intervals that can be recognized and traced on the basis of distinctive acoustic attributes such as reflection intensity, coherency, spacing, and unit geometry (Syvitski and Praeg, 1989). Estimates of sediment thickness are based upon an assumed sound velocity of 1500 $m \cdot s^{-1}$, so that a two-way travel time of 100 ms is equivalent to 75 m. However, acoustic velocities in the sediments described here may range from 1600 $m \cdot s^{-1}$ or less in mud to 3000 $m \cdot s^{-1}$ or more in compact material such as glacial diamicton. Therefore, the true thickness of some sections, particularly in unit 2, may be greater than the value quoted. The acoustic units are described below.

Unit 1 (bedrock)

Unit 1 forms acoustic basement. On some air gun and Huntec seismic reflection profiles, it contains parallel, internal reflections, often dipping or folded. On other profiles, it has a dense tone and incoherent reflections. These contrasts are illustrated in Figure 4, which shows a profile across the inner shelf just north of Cape Freels. Quaternary deposits overlie Late Cretaceous to Tertiary coastal-plain rocks such as siltstone, sandstone, shale, and mudstone (Fader et al., 1989), which display strong acoustic stratification. The underlying Lower Paleozoic rocks of the Appalachian Orogen (Devonian granite) form acoustic basement.

On sidescan sonograms, unit 1 is typically strongly reflective and the positive relief casts sharp acoustic shadows. Patterns similar to joint and bedding-plane patterns in exposed bedrock are commonly observed.

On the map of surficial sediments (Fig. 1), unit 1 is very close to the seabed in the zone described as 'bedrock predominant'. Outcrops are typically overlain by thin (<1 m), discontinuous layers of mud or sandy mud, with ice-rafted, angular gravel or sand and gravel. Greater thicknesses of sediment may also be found in small basins, pockets, and crevices aligned along joints and faults. Even in shallow water, outcrops of unit 1 may have a veneer of cobbles and boulders and complete exposures are comparatively rare.

Unit 2 (glacial diamicton)

On seismic reflection profiles, unit 2 has a dense grey tone due to incoherent reflections (Fig. 7). As a rule, it has no coherent, internal reflections, but in a few places (e.g. parts of White Bay and in central Notre Dame Bay), irregular, quasi-horizontal reflections separate wedges of the unit. It commonly has a positive relief and may occur as isolated mounds several metres high, as ridges, or as extensive, wedge-shaped sheets. Above a depth of 200 m, its surface typically is highly irregular due to the presence of iceberg furrows. Sidescan sonograms show numerous, crosscutting, arcuate iceberg furrows, each one comprising a central trough with two parallel berms (Fig. 8). Only two cores intersected unit 2 (*see* below). The bottom of core 91026-042 contained randomly oriented, subangular pebbles in a stiff matrix of dark grey, sandy, silty clay. The bottom of core 90013-054 (Fig. 9) consisted of angular pebbles and grit in a matrix of reddish, sandy, silty clay.

Unit 2 is exposed over extensive areas of the seabed well offshore from the coast in the central and eastern areas of the study region. A large, wedge-shaped deposit up to 40 m thick occurs on the north flank of Notre Dame Channel. A ridge extends to the southwest and lies off the east coast of Baie Verte Peninsula (Fig. 7), where it is mantled by thin, glaciomarine and postglacial deposits. Due south of Tilt Cove, acoustic profiles from survey cruise 75009 seem to show the acoustically incoherent ridge interfingering with stratified sediments of unit 3. Ridges of unit 2 also occur in places on the south flank of Notre Dame Channel.

Northwest of New World Island, unit 2 occurs in the Notre Dame Channel as three discrete sheets with thicknesses of 45 m, 10 m, and 25 m (from the base upward) and fills a V-shaped bedrock valley that has a maximum depth of 555 m (this valley lies several kilometres south of the axis of the basin on the seabed, so that the Quaternary sediments thin northward towards the basin axis). Unit 2 also forms cross-valley moraine ridges in the Bay of Exploits (Fig. 10) and Baie Verte. In the Hamilton Sound area, it forms a veneer with scattered drumlins up to 8 m thick (Shaw and Edwardson, 1994).

Unit 3 (stratified, glaciomarine sediment)

Unit 3 shows three acoustic facies. Facies 1 (Fig. 7, 9, 11) has moderate- to high-intensity, continuous, coherent reflections that are highly conformable to the underlying terrain (commonly unit 2) and contains scattered point-source reflections. It has an average thickness of about 5 m, but is thinner on highs than in basins. It is found throughout the region, but is rare above approximately 50 m water

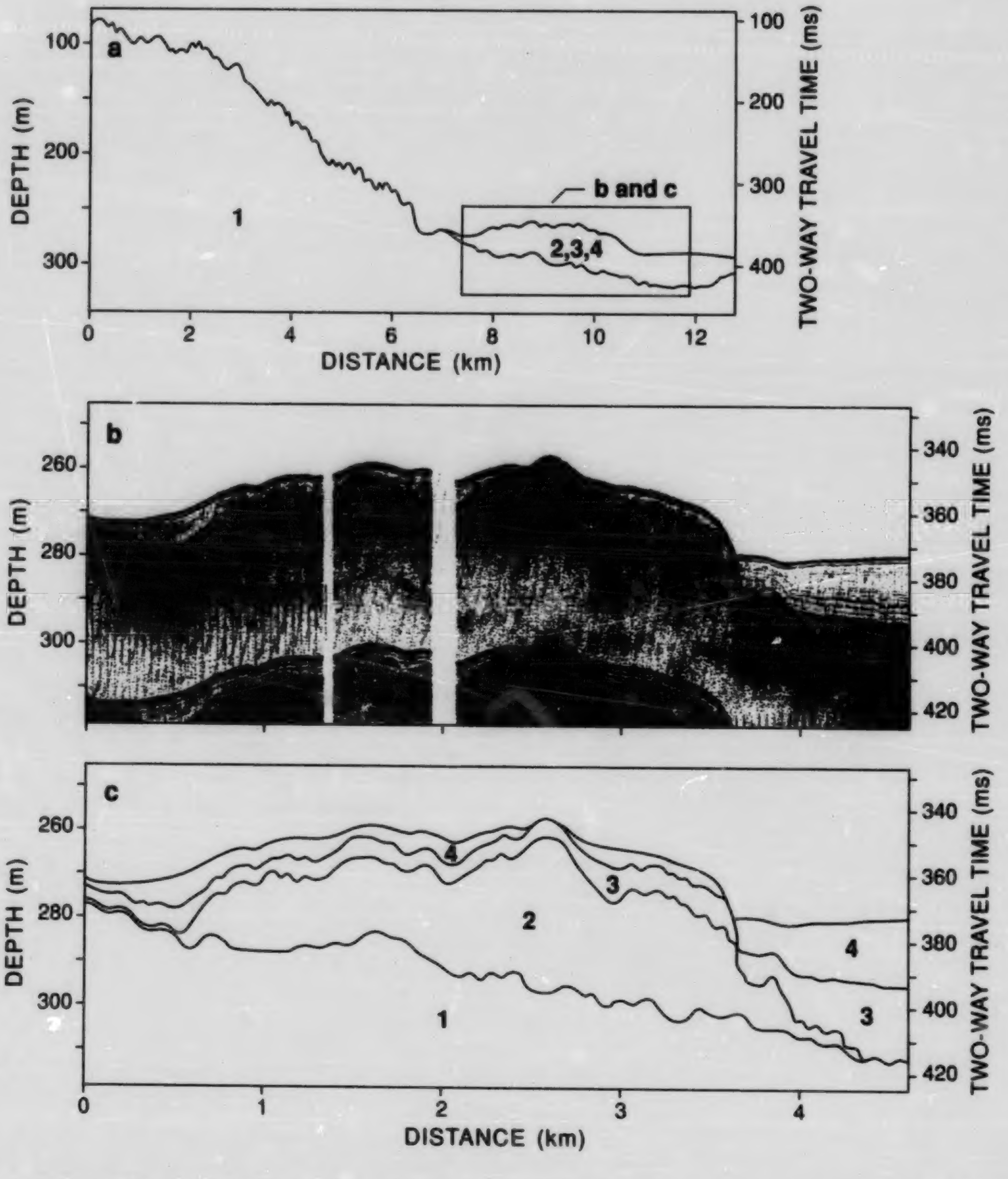


Figure 7. *A ridge of unit 2 (glacial diamicton) east of Baie Verte Peninsula in water depths of 260–300 m is overlain by a drape of unit 3 (stratified, glaciomarine mud) and unit 4 (postglacial mud). Unit 4 has an erosional upper surface except in the basin at the right. The location of this profile is shown in Figure 1.*

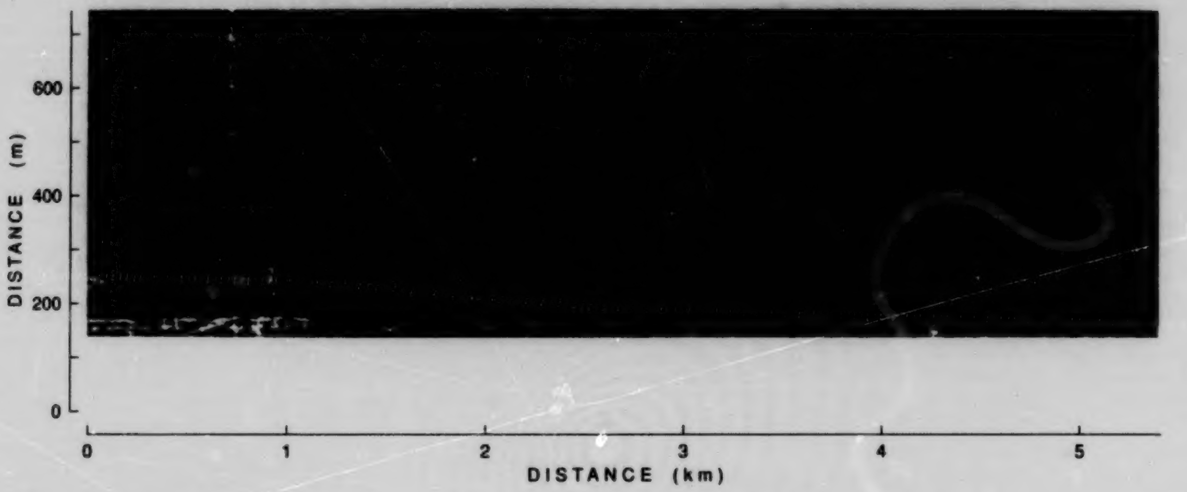


Figure 8. *BIO sidescan sonar record from the northern flank of Notre Dame Channel, showing intense iceberg scouring of the seabed. Water depth is approximately 170 m. The range of this sidescan system is 750 m. The location of this profile is shown in Figure 1. Cruise 78023, day/time 212/15:40–16:10*

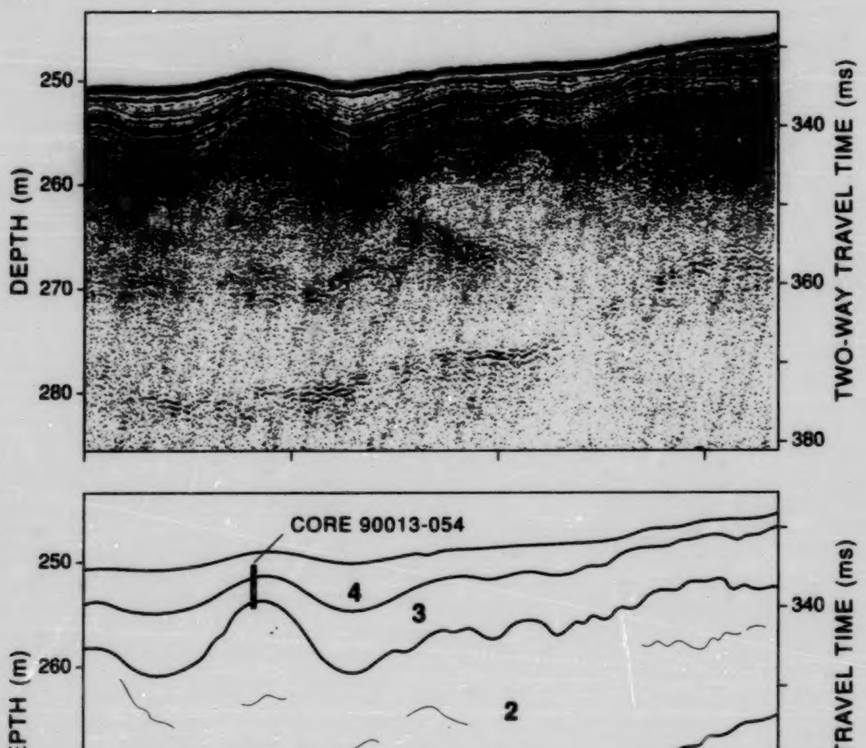


Figure 9.

Huntec profile showing a layer of postglacial mud (unit 4) with weak, continuous, coherent, internal reflections that are truncated at the seabed. Below this layer is a drape of glaciomarine mud (unit 3) that displays strong, parallel, continuous, coherent, internal reflections. A 20 m thick layer of glacial diamicton (unit 2) shows several internal reflections. The bedrock (unit 1) is probably lower Carboniferous sedimentary rocks, according to the map of Fader et al. (1989). The location of core 90013-054 is indicated. The location of this profile is shown in Figure 1.

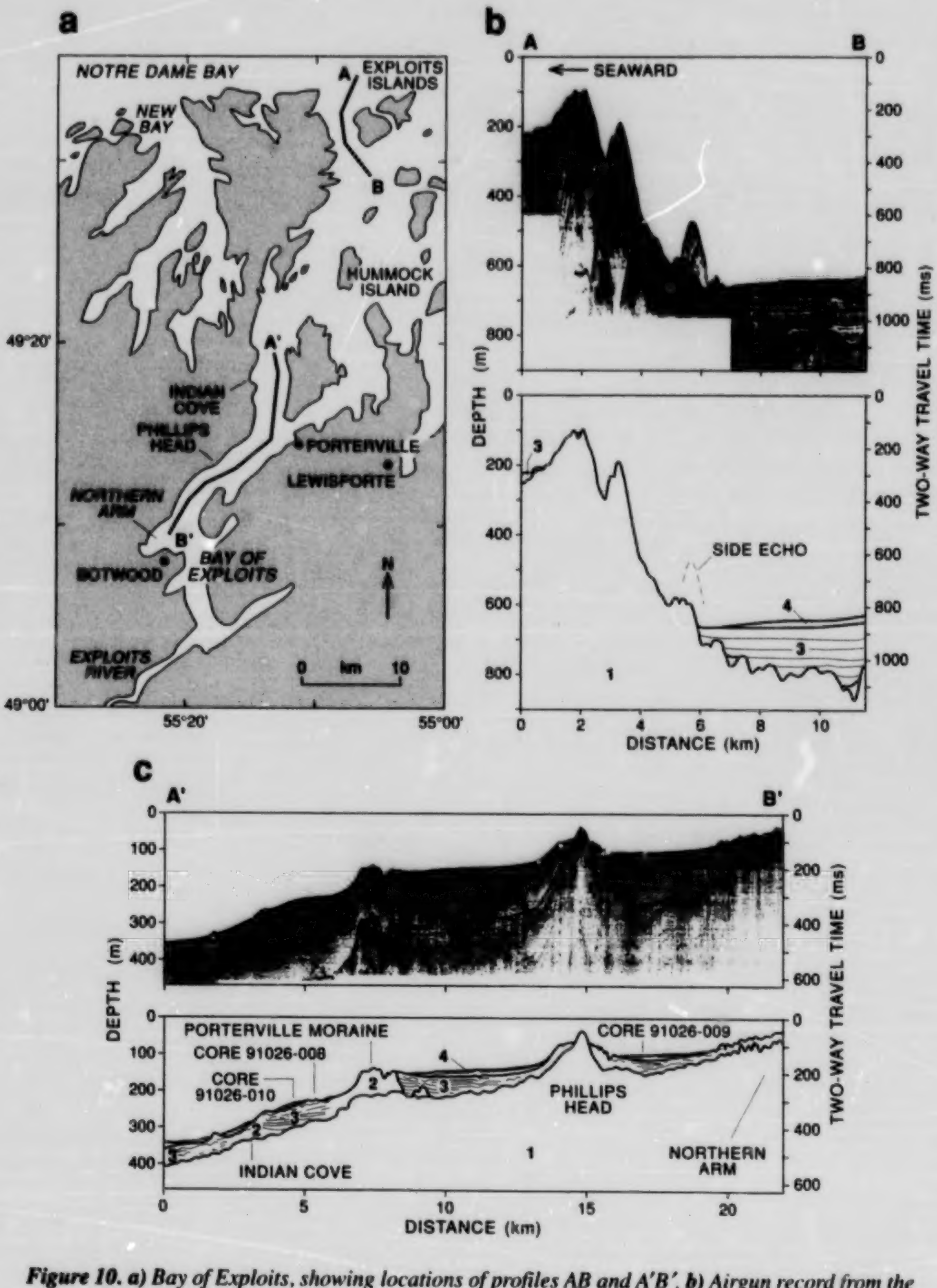


Figure 10. *a) Bay of Exploits, showing locations of profiles AB and A'B'. b) Airgun record from the mouth of Bay of Exploits, showing the relatively shallow bedrock sill and the ponded sediments of unit 3 (facies 2) in a deep basin. c) Airgun transect along the inner part of Bay of Exploits showing a small, buried moraine ridge at Indian Cove, a major moraine exposed on the seabed at Porterville, and possible moraine deposits flanking a bedrock ridge at Phillips Head.*

depth. As noted above, unit 3 deposits interfinger with a wedge of unit 2 east of Baie Verte Peninsula, on the flank of Notre Dame Channel.

Facies 2 of unit 3 contains acoustically transparent intervals that are commonly several metres thick, but up to 20 m thick in several fiords (Fig. 12, 13). The upper surfaces of the transparent intervals commonly have small-scale roughness. The acoustically transparent intervals are generally interleaved with stratified sediments, but they also display abrupt lateral transitions into stratified sediments. Facies 2 occurs just outside the mouths of fiords, but is found mainly within them, in Green Bay, Halls Bay, Seal Bay, New Bay, Badger Bay, and the Bay of Exploits. It occurs as elongated, basin-fill deposits that attain a maximum thickness of 150 m in Green Bay and are invariably capped by facies 1.

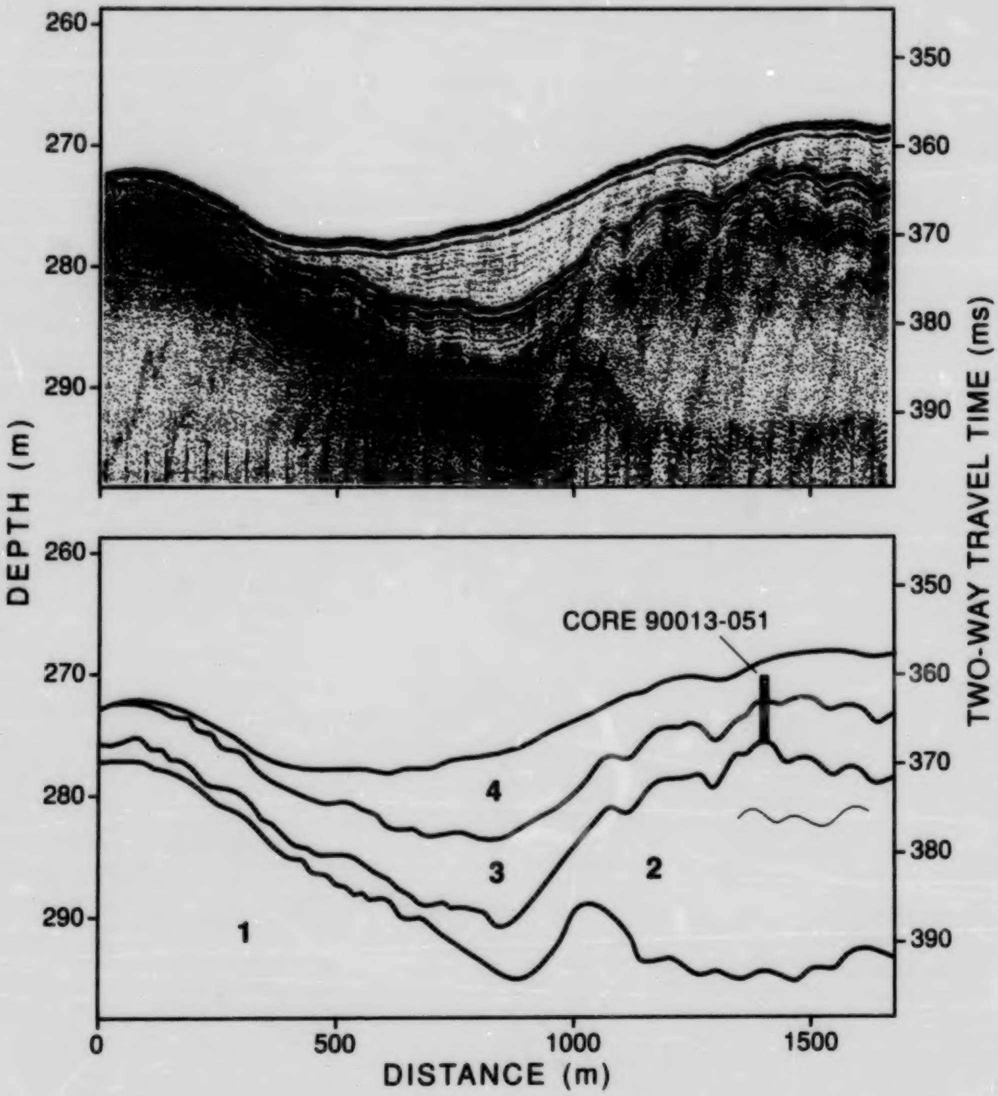


Figure 11. Huntec profile showing a layer of unit 4 sediments (postglacial mud) with weak, continuous, coherent, internal reflections that are truncated at the seabed. The postglacial mud overlies a draped deposit of unit 3 (glaciomarine mud). The glacial diamicton (unit 2) is part of the ridge located east of Baie Verte Peninsula. The location of piston core 90013-051 is shown. The location of this profile is shown in Figure 1.

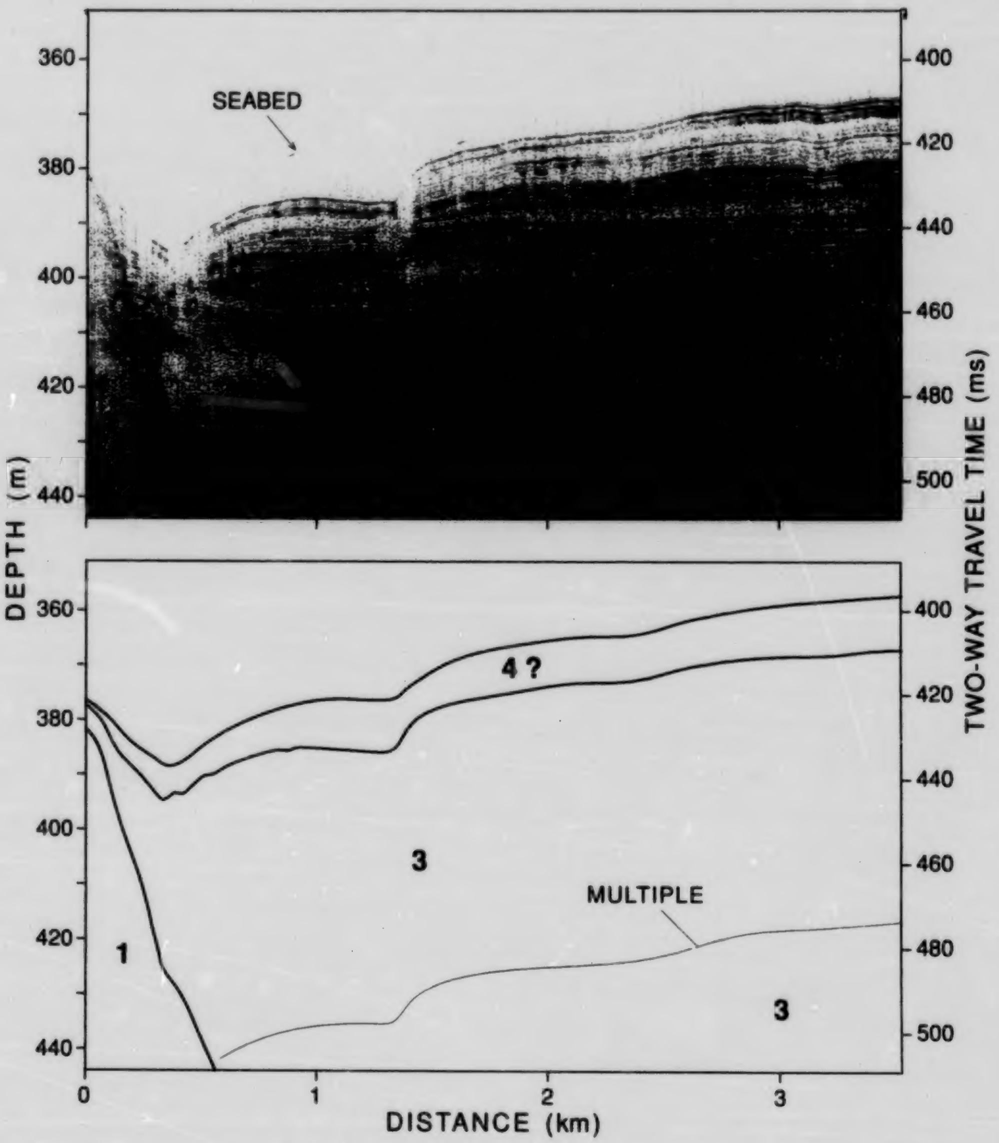


***Figure 12.** Huntec record showing stratified sediments of unit 3 (facies 2) near Springdale, in Halls Bay. The ponded, glaciomarine sediments are 150 m thick. Layers with strong, continuous, coherent, internal reflections are interleaved with acoustically transparent layers that are locally wedge-shaped and commonly have a rough upper surface. This subfacies is interpreted as being composed of interbedded, glaciomarine, hemipelagic sediments (acoustically stratified), derived from buoyant meltwater plumes, and of debris-flow deposits (acoustically transparent). The seabed does not show clearly on this reproduction of the Huntec record. The location of this profile is shown in Figure 1.*

Facies 3 of unit 3 occurs towards the heads of Halls Bay and the Bay of Exploits (Botwood area) and may occur elsewhere. It comprises stratified sediments similar in appearance to facies 2, but is contorted due to movement along slip planes (Fig. 14).

Unit 4 (postglacial mud)

Close to its base, unit 4 has low-intensity, ponded to conformable, closely spaced, internal reflections; the intensity weakens upward, making it acoustically transparent (Fig. 15). In shallower areas, the top of the unit has been eroded, presumably by currents, producing an angular unconformity at the seabed (Fig. 16; *see also* Fig. 9, 11). Elsewhere, the unit thins towards basin flanks, perhaps due to syndepositional processes. In parts of White Bay (*see* Fig. 16), subsequent onlapping sedimentation buried the unconformity. Lateral extrapolation of reflections of known age in core 90013-035 shows that the unconformity probably formed in the interval 6–4 ka BP.

Thick deposits of unit 4 occur in the deepest basins, principally in Notre Dame Bay (up to 45 m thick) and White Bay (up to 35 m in the north and 55 m in the south). Thinner

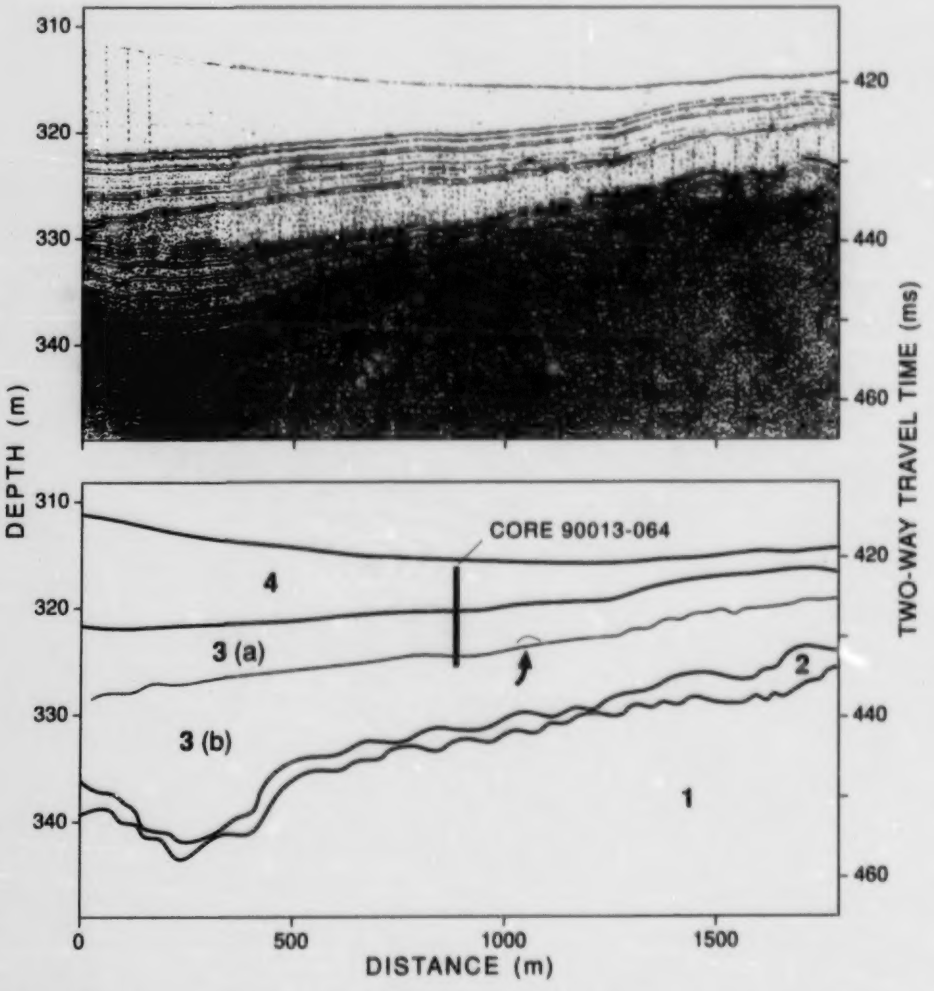


Figure 13. *Huntec record showing acoustically transparent postglacial mud (unit 4) overlying glaciomarine sediments of unit 3. The uppermost part of unit 3 belongs to facies 1 and contains a point-source reflection (a). The lower glaciomarine deposit is ponded and is assigned to facies 2. The prominent, acoustically transparent interval was probably produced as a result of a debris flow. The irregular upper surface of the flow is evident (b). Also shown is the location of core 90013-064. The location of this profile is shown in Figure 1.*

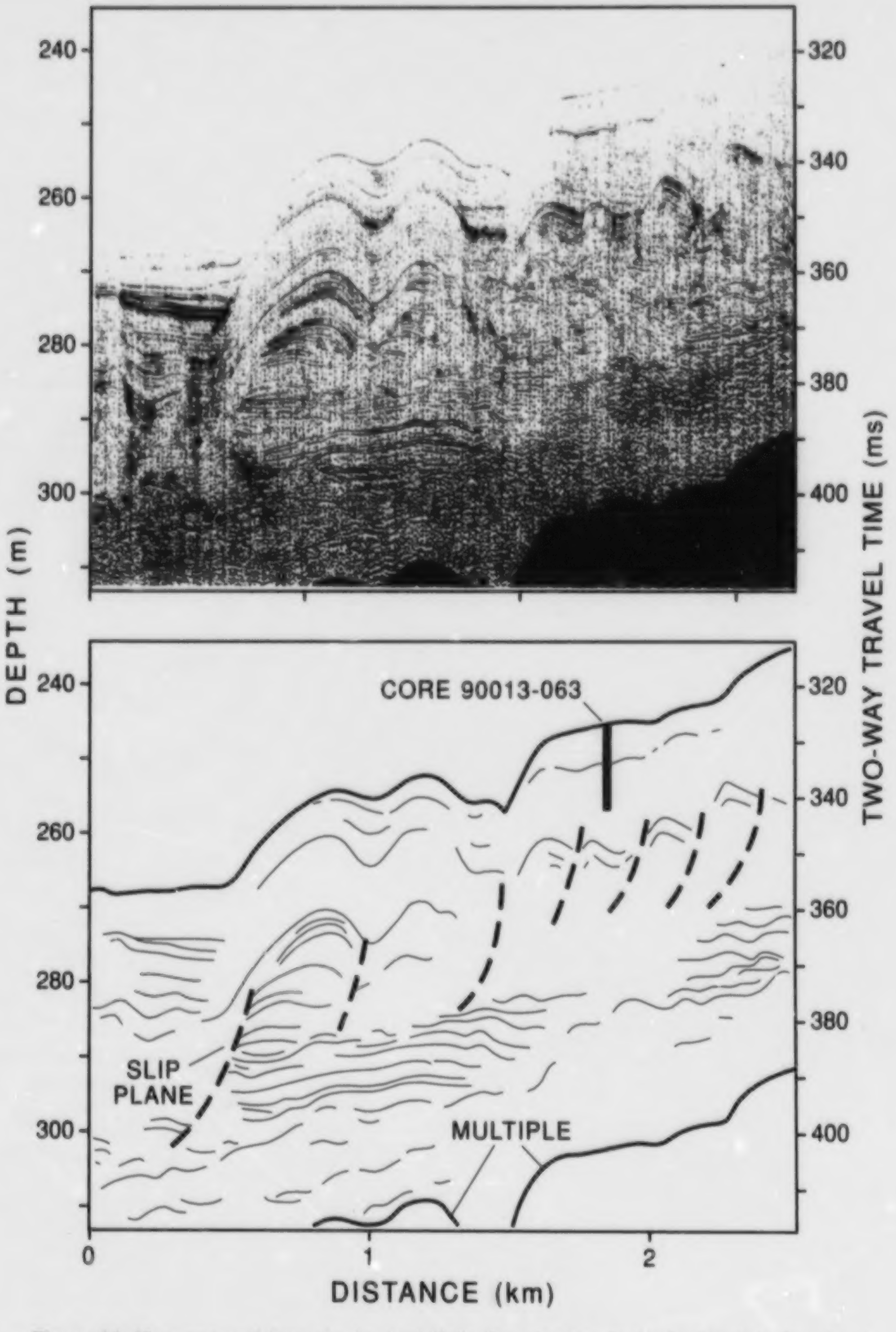


Figure 14. *Huntec record from the head of Halls Bay showing facies 3 of unit 3. Prominent acoustic reflections are shown on the interpretation. The sediments contain strong, continuous, coherent, internal reflections. They were deformed by slumping and slipping, which probably occurred at the final stage of deglaciation, when relative sea level was dropping quickly from the late-glacial maximum. Shell at 4 m in core 90013-063 is dated at 11 330 ± 130 BP (TO-3170). The location of this profile is shown in Figure 1.*

deposits are found in sheltered, coastal basins such as Gander Bay and Baie Verte. Small pockets and veneers occur in areas mapped as predominantly bedrock. Where unit 4 is very thin, it commonly contains relatively high amounts of angular, ice-rafted gravel. Unit 4 occurs in fiords, in which it is relatively thin except in some outer-fiord areas where, because of strong currents, it is banked against one or the other sidewall. It is commonly absent on the central axis of the fiord, where the underlying glaciomarine sediments are exposed (unit 3).

Unit 5 (postglacial sand and gravel)

In shallow water (<60 m), unit 5 is the uppermost unit and is composed of sand and/or gravel. Where the sand is fine and mixed with mud, unit 5 has some acoustic stratification (e.g. in Hamilton Sound), but coarser grain sizes inhibit penetration by subbottom profilers. Unit 5 includes 1) well sorted sand with shell hash and scattered pebbles, with wave- and current-generated bedforms including ripples and dunes, 2) thin sheets of rippled, mobile, poorly sorted,

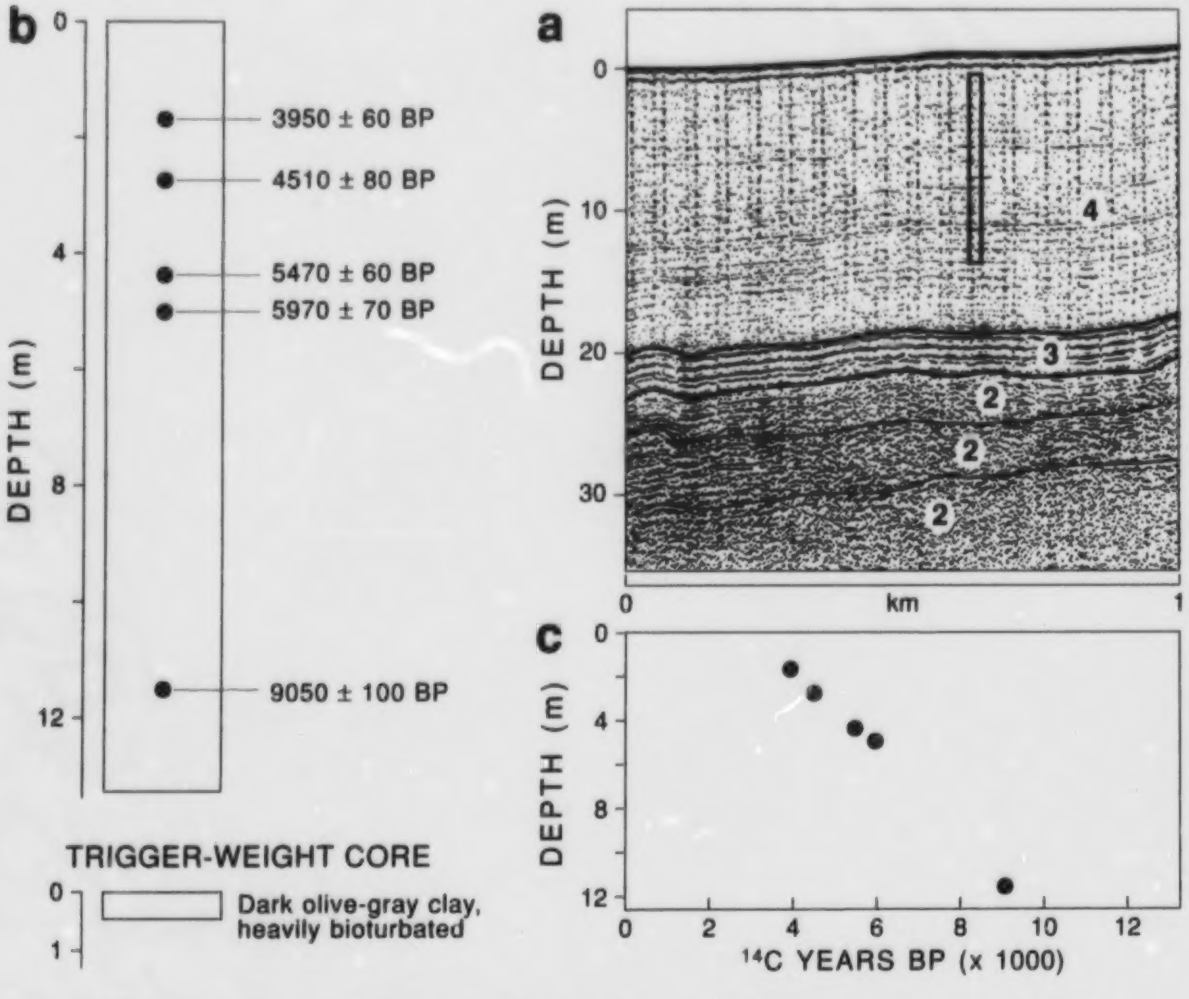


***Figure 15. a)** Huntec record from White Bay showing a relatively thick deposit of unit 4 (postglaciol mud) overlying a drape of unit 3 (stratified, glaciomarine mud) and multiple sheets of unit 2 (glacial diamicton). The location of this profile is shown in Figure 1. **b)** AMS radiocarbon dates on shell samples from core 90013-035. **c)** Plot of depth versus age.*

sandy gravel, 3) veneers of largely immobile (*Lithothamnion*-coated) gravel overlying glacial diamicton, and 4) shoreface prisms of sand or muddy sand that pass laterally into beaches. Unit 5 is found in shallower parts of the zone of predominant bedrock, in pockets (Fig. 17), in discontinuous veneers, or as shoreface sheets. The most extensive areas of unit 5 are in the northeast, off The Straight Shore and in Hamilton Sound.

Lithostratigraphy and radiocarbon chronology

This section contains descriptions of core data, organized by cruise. Simplified lithostratigraphic logs are shown in Figure 18, together with the position and ages of radiocarbon-dated samples, typically marine pelecypods. Further information on radiocarbon-dated samples is given in Table 1.

Core data: cruise 90013 (CSS *Hudson*)

Piston core 035 was collected in White Bay in a water depth of 367 m. Acoustic data (Fig. 15) show three layers of unit 2 (glacial diamicton) with a combined thickness of 15 m, overlain by 5 m of unit 3 (stratified, glaciomarine sediment) and 20 m of unit 4 (postglacial mud). The core consists entirely of unit 4 and comprises extensively bioturbated, olive-grey, silty clay with small amounts of angular pebbles and granules below 6.3 m. Four accelerator mass spectrometry (AMS) dates on marine pelecypods from the upper part of the core reveal a nearly linear average sedimentation rate of 1.75 m/ka during the period 6–4 ka. Extrapolation of that rate dates the top of the core at 3 ka. Either the top 5 m were lost during coring or the sedimentation rate declined after 4 ka. If we take into account the lower radiocarbon age of 9050 ± 100 BP, then an alternative (and preferred) interpretation of the data is that the sediment accumulation rate was

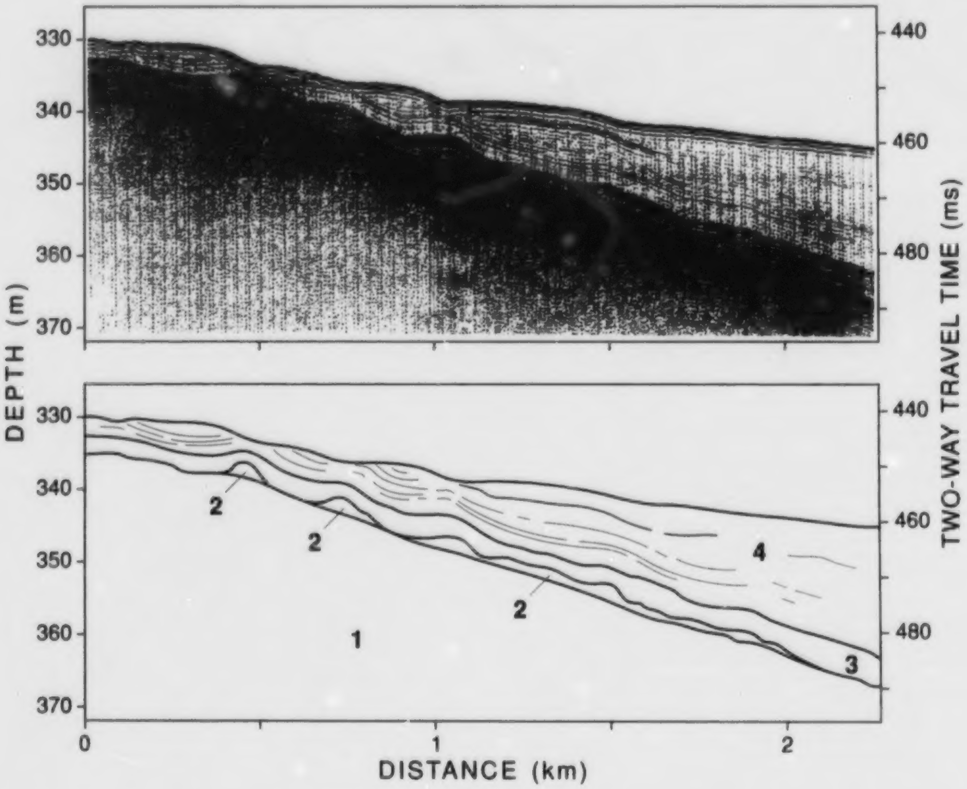
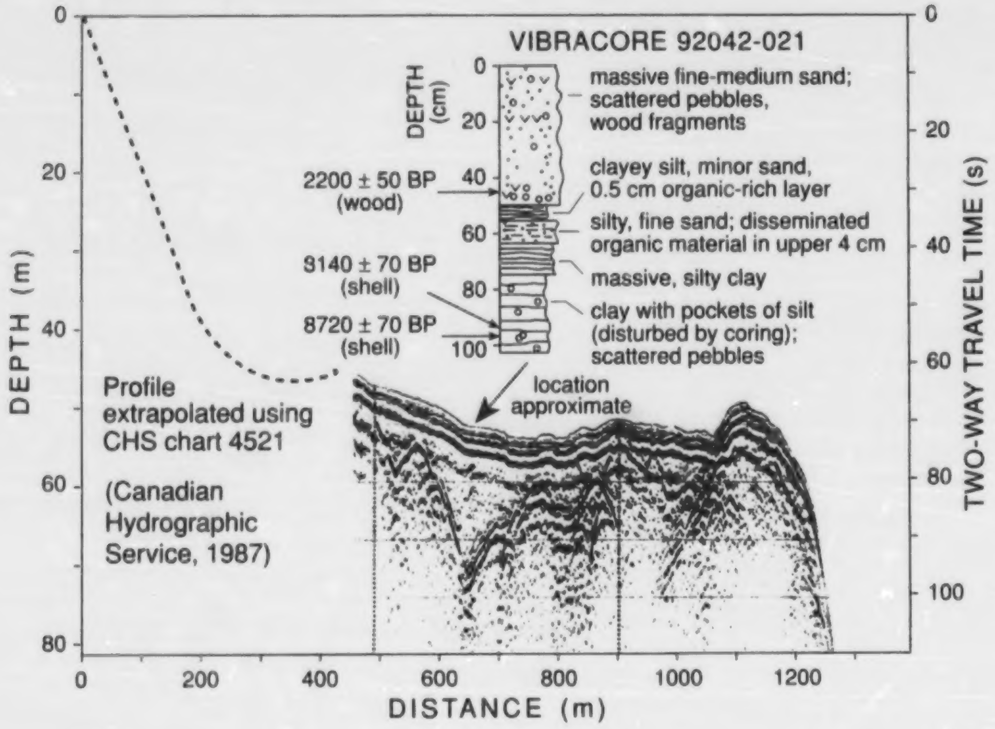


Figure 16. Huntec record from White Bay showing unit 4 sediments (postglacial mud) that have been eroded at the seabed in relatively shallow water (left). In contrast, postglacial sedimentation was uninterrupted in the deeper basin (right). A thin sheet of unit 3 (glaciomarine mud) overlies small ridges or mounds of unit 2 (glacial diamicton) that overlie unit 1 (bedrock). Some internal reflections within unit 4 have been enhanced to assist interpretation. The location of this profile is shown in Figure 1.


VIBRACORE 92042-021
DEPTH (cm)
0
20
40
60
80
100
massive fine-medium sand; scattered pebbles, wood fragments
clayey silt, minor sand, 0.5 cm organic-rich layer
silty, fine sand; disseminated organic material in upper 4 cm
massive, silty clay
clay with pockets of silt (disturbed by coring); scattered pebbles
2200 ± 50 BP (wood)
8140 ± 70 BP (shell)
8720 ± 70 BP (shell)
location approximate
Profile extrapolated using CHS chart 4521
(Canadian Hydrographic Service, 1987)
DEPTH (m)
0
20
40
60
80
TWO-WAY TRAVEL TIME (s)
0
20
40
60
80
100
DISTANCE (m)
0
200
400
600
800
1000
1200

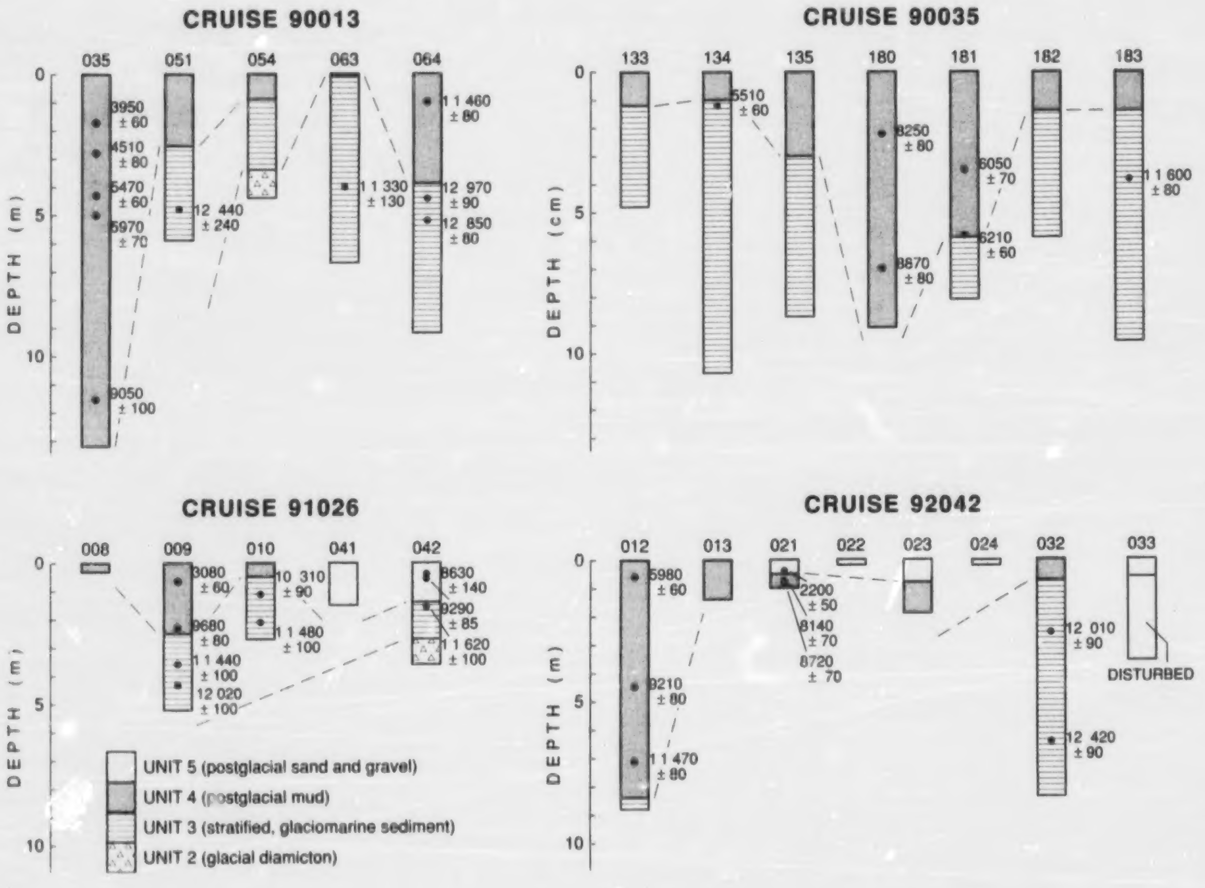

CRUISE 90013
035
051
054
063
064
DEPTH (m)
0
5
10
3950 ± 60
4510 ± 80
5470 ± 60
5970 ± 70
9050 ± 100
12 440 ± 240
11 330 ± 130
11 460 ± 80
12 970 ± 90
12 850 ± 80
CRUISE 90035
133
134
135
180
181
182
183
DEPTH (cm)
0
5
10
5510 ± 60
8250 ± 80
8870 ± 80
6050 ± 70
6210 ± 60
11 600 ± 80
CRUISE 91026
008
009
010
041
042
DEPTH (m)
0
5
10
3080 ± 60
9680 ± 80
11 440 ± 100
12 020 ± 100
10 310 ± 90
11 480 ± 100
8630 ± 140
9290 ± 85
11 620 ± 100
CRUISE 92042
012
013
021
022
023
024
032
033
DEPTH (m)
0
5
10
5980 ± 60
9210 ± 80
11 470 ± 80
2200 ± 50
8140 ± 70
8720 ± 70
12 010 ± 90
12 420 ± 90
DISTURBED
UNIT 5 (postglacial sand and gravel)
UNIT 4 (postglacial mud)
UNIT 3 (stratified, glaciomarine sediment)
UNIT 2 (glacial diamicton)

Figure 17.

Low-frequency (geopulse bubble pulser) seismic reflection profile off Deer Cove, Baie Verte, showing a pocket of unit 5 (postglacial sand and gravel) trapped between a bedrock shoal and the coast. The seabed sediment consists of well sorted, medium sand forming a thin (<0.5 m) layer that is difficult to observe because of the ringing effect on the record. This layer overlies acoustically transparent sediments, possibly units 4 and 3. Also shown is the location and lithological log of vibracore 92042-21 and radiocarbon ages of samples from the core.

nonlinear and decelerated throughout the Holocene, in which case the top of the core dates to about 2 ka and only the top 1.2 m of the core was lost during coring (which is a more reasonable loss; *see* Buckley et al., 1994). On the basis of this interpretation of the data, we conclude that the youngest glaciomarine sediments at the site of piston core 035 are 10.7 ka.

Piston core 051 (Notre Dame Bay, water depth 268 m) intersected unit 3 (stratified, glaciomarine sediment) and unit 4 (postglacial mud) where they overlie a bank of unit 2 (glacial diamicton) off the east coast of Baie Verte Peninsula (Fig. 11). The sediment below 2.55 m in the core is believed to be unit 3 (stratified, glaciomarine sediment). A shell at 4.78 m is dated at 12 440 ± 240 BP. Sediment from 2.55 to 2.67 m is a dark grey to olive-grey to greyish-brown, sandy, gravelly clay, bioturbated in places, laminated elsewhere, capped by a layer of medium sand with subangular to angular gravel. The upper part of the core, from 0.00 to 2.55 m, consists of bioturbated, light olive-grey mud with a few scattered clasts of fine gravel and a small amount of sand (unit 4).

The location of piston core 054 (Notre Dame Bay, water depth 257 m) is shown in Figure 9. Sediment below 3.37 m is diamicton, a red clay matrix containing a high concentration of poorly sorted, angular gravel and sand. It is interpreted as unit 2 (glacial diamicton). Material between 0.92 and 3.37 m is sandy, gravelly clay with numerous darker laminae commonly 1 to 2 mm thick, but up to 7 mm thick, that are dark grey to reddish brown. Some laminae contain clay pellets, typically 1 mm in diameter. This interval is interpreted as unit 3 (stratified, glaciomarine sediment). Sediment from 0.00 to 0.92 m is a bioturbated, olive-grey clay with scattered grit and pebbles (unit 4, postglacial mud). Radiocarbon ages are not available for this core.

Figure 18.

Abbreviated lithological logs of cores collected during four cruises off northeast Newfoundland. Also shown are radiocarbon ages, primarily for marine pelecypods. Detailed descriptions of the radiocarbon data are given in Table 1. Note the different scale for 90035 cores.

Piston core 063 was collected near Springdale, Halls Bay, from a water depth of 246 m (Fig. 14). The core consists almost entirely of dark grey clay with a high concentration of grit and pebbles (unit 3, glaciomarine mud). Bioturbation is intense below 2.10 m. A layer of gravelly sand extends from 4.96 to 4.98 m. The seismic reflection profile shows well stratified sediments of unit 3. A shell valve at 4.00 m is dated at 11 330 ± 130 BP. The core is capped by a 0.09 m thick layer of dark olive-grey silt (unit 4).

The location of piston core 064 (Notre Dame Bay, water depth 316 m) is shown in Figure 13. Sediment below 3.89 m is predominantly dark reddish-grey clay, laminated in places, with grit and gravel (unit 3). A layer of interlaminated, medium sand and silt at 4.23 to 4.27 m grades upward into the clay. Below 5.63 m, convoluted grey and reddish-brown clay are interbedded. Sediment from 0.00–3.89 m is weakly bioturbated, olive-grey clay with scattered, fine gravel (unit 4).

Grain-size analysis (ten samples) showed little variation throughout the core (Fig. 19) in terms of the proportion of clay and silt (generally 60:30) with the exception of the sample from interlaminated, medium sand and silt at 4.23 to 4.27 m. Foraminiferal analysis shows the occurrence of three zones (Fig. 20) as follows: 1) a zone below 7.5 m with less than 100 tests per 10 cm^3 of sediment that is interpreted as representing a glaciomarine environment with high levels of glacial meltwater; 2) a zone from 6.5 to 7.5 m in which *Cassidulina reniforme* and *Elphidium excavatum* are co-dominant, which is believed to indicate an ice-marginal environment with temperature and salinity about 0°C and 25–30 ‰ respectively; and 3) a zone above 7.5 m that is distinguished mainly by the presence of relatively large percentages of *Fursenkoina fusiformis* and lesser amounts of other species, in addition to the two species noted above, and that is indicative of an ice-distal environment.

Magnetic susceptibility measurements (Fig. 19) show two zones, one of relatively low magnetic susceptibility from the top down to about 4 m and another below 4 m of higher, but fluctuating, magnetic susceptibility. A prominent spike of high magnetic susceptibility marks the sandy zone at 4.23 to 4.27 m. The seismic reflection data show that unit 3 contains debris flows. The core is believed to have penetrated disturbed debris-flow sediments below 5.63 m. Shells contained in this core have radiocarbon ages of 12 850 ± 80 BP (5.22 m, unit 3), 12 970 ± 90 BP (4.45 m, unit 3), and 11 460 ± 80 BP (1.98 m, unit 4).

Table 1. Information on AMS radiocarbon dates obtained for this study. Shell dates have been given a reservoir correction of 410 years, equivalent to fractionation correction to a base $\delta^{13}C = 0‰$.

Sample number	Material	Laboratory number	X^{13}C = 25X	X^{13}C = 0X	Location
90013-035-170	One specimen of *Tachyrhynchus erosus*; slightly eroded	TO-3158	4360 ± 60	3950 ± 60	White Bay
90013-035-275	One specimen of *Propebela elegans*; eroded	TO-3169	4920 ± 80	4510 ± 80	White Bay
90013-035-438	One valve of *Megayoldia thraciaeformis*	TO-3157	5880 ± 60	5470 ± 60	White Bay
90013-035-498	Unidentified pelecypod fragments, fresh	TO-3173	6380 ± 70	5970 ± 70	White Bay
90013-035-1156	Unidentified pelecypod fragments	TO-3861	9460 ± 70	9050 ± 100	White Bay
90013-051-478	Juvenile gastropod (*Buccinum* sp.)	TO-3155	12 850 ± 240	12 440 ± 240	Notre Dame Bay
90013-063-400	Broken valve of *Nucula* sp.	TO-3170	11 740 ± 130	11 330 ± 130	Halls Bay
90013-064-198	Complete *Macoma calcarea*	TO-2400	11 870 ± 80	11 460 ± 80	Notre Dame Bay
90013-064-445	One valve and a fragment of *Nucula tenuis*	TO-2399	13 380 ± 90	12 970 ± 90	Notre Dame Bay
90013-064-522	Six specimens and one valve of *Nucula tenuis*; one juvenile *Neptunea* sp.	TO-2401	13 260 ± 80	12 850 ± 80	Notre Dame Bay
90035-134-12	Two unidentified gastropods	TO-2402	5920 ± 60	5510 ± 60	Baie Verte
90035-180-22	One complete *Nuculana pernula*	TO-2398	8660 ± 80	8250 ± 80	Halls Bay
90035-180-70	One complete *Macoma calcarea*	TO-2397	9280 ± 80	8870 ± 80	Halls Bay
90035-181-35	One complete *Macoma calcarea*	TO-2396	6460 ± 70	6050 ± 70	Halls Bay
90035-181-58	Fragments of *Macoma* sp.	TO-3863	6620 ± 60	6210 ± 60	Halls Bay
90035-183-38	One complete *Macoma calcarea*	TO-2395	12 010 ± 80	11 600 ± 80	Halls Bay
91026-009-065	One specimen of *Yoldia limatula*	Beta-51670 ETH-9465	3490 ± 60	3080 ± 60	Bay of Exploits
91026-009-230	Pelecypod fragments including *Hiatella arctica*	TO-3864	10 090 ± 80	9680 ± 80	Bay of Exploits

Core data: cruise 90035 (CSS *Navicula*)

All cores collected during this survey were gravity cores. Three cores collected in Baie Verte show close correspondence between lithology and acoustic character as observed on Seistec profiles. Core 133 (depth 36 m) contains grey clay with scattered, angular pebbles and grit (unit 3) overlain by 0.12 m of dark olive-grey, gravelly, sandy mud (unit 4). In core 134 (depth 69 m), sediment from 0.10 to 1.07 m is light grey clay with disseminated angular gravel and grit (unit 3). Shell material at 0.12 m is dated at 5510 ± 60 BP. The uppermost layer (0.00–0.10 m) is dark olive-grey, silty mud with a few pebbles and scattered shell fragments (unit 4). The third core from Baie Verte, core 135 (depth 63.5 m), contains grey clay with disseminated, angular gravel and grit (unit 3). The uppermost layer (0.00–0.30 m) is dark olive-grey, sandy mud with scattered gravel that coarsens upward and has a layer of pebbles at its base (unit 4).

The four cores (cores 180–183) collected in the Sunday Cove Island area also show close correspondence between lithology and acoustic character. All of core 180 (depth 103 m) is interpreted as unit 4. It consists of olive-grey clay with a few scattered pebbles. Shell material is dated at 8870 ± 80 BP (0.70 m) and 8250 ± 80 BP (0.22 m). The seismic reflection profile shows 2 m of unit 4 separated from the underlying unit 3 by an erosional unconformity (which must therefore predate 8.9 ka). In core 181 (depth 149 m), sediment below 0.59 m is faintly laminated grey clay with grit and angular gravel (unit 3). A thin layer of fine, gravelly sand (0.55–0.59 m) with sharp upper and lower boundaries marks the unconformity seen on acoustic data. The interval from 0.00 to 0.55 m is olive-grey mud (unit 4).

In core 182 (180 m), the sediment below 0.14 m is reddish-grey clay with angular gravel and grit (unit 3). The interval from 0.00 to 0.14 m is olive-grey, sandy, silty mud

Table 1. (cont.)

Sample number	Material	Laboratory number	X^{13}C = 25X	X^{13}C = 0X	Location
91026-009-356	One specimen of *Nuculana pernula* (Miller)	Beta-51671 ETH-9466	11 850 ± 100	11 440 ± 100	Bay of Exploits
91026-009-423	Fragments of *Hiatella arctica*	Beta-51672 ETH-9467	12 430 ± 100	12 020 ± 100	Bay of Exploits
91026-010-111	Fragments of a gastropod, either *Natica* sp. or *Lunatia* sp.	Beta-51673 ETH-9468	10 720 ± 90	10 310 ± 90	Bay of Exploits
91026-010-206	One specimen of *Nuculana pernula*	Beta-51674 ETH-9469	11 890 ± 100	11 480 ± 100	Bay of Exploits
91026-042-042	One specimen of *Mya truncata* (Linne)	Beta-51675	9040 ± 140	8630 ± 140	Hamilton Sound
91026-042-051	Bryozoan fragments	Beta-51676 ETH-9470	9700 ± 85	9290 ± 85	Hamilton Sound
91026-042-159	One specimen of *Natica clausa*	Beta-51677	12 030 ± 100	11 620 ± 100	Hamilton Sound
92042-012-63	Two specimens of *Siphonodentalium lobatum*; one specimen of *Portlandia arctica*; fragments of *Yoldiella* sp. and *Macoma* sp.	TO-3857	6390 ± 60	5980 ± 60	New Bay
92042-012-445	Three specimens and three fragments of *Nucula tenuis*	TO-3858	9620 ± 80	9210 ± 80	New Bay
92042-012-711	One broken bivalve, probably *Nuculana* sp.	TO-3854	11 880 ± 80	11 470 ± 80	New Bay
92042-021-47	Unidentified bark fragments	TO-3852	2200 ± 50	-	Deer Cove
92042-021-93	Fragments of *Mercenaria mercenaria* One valve of *Nuculana buccata*	TO-3853	8550 ± 70	8140 ± 70	Deer Cove
92042-021-98	One valve of *Cerastoderma pinnulatum*	TO-3860	9130 ± 70	8720 ± 70	Deer Cove
92042-032-257	*Yoldia sapotilla* fragments (fresh)	TO-3859	12 420 ± 90	12 010 ± 90	Badger Bay
92042-032-646	One complete specimen of *Nucula tenuis*	TO-3855	12 830 ± 90	12 420 ± 90	Badger Bay

(unit 4). A fourth core from this area (core 183, depth 181 m) contains grey to reddish-grey clay with grit and angular pebbles below 0.14 m (unit 3). Shell at 0.38 m is dated at 11 600 ± 80 BP. Sediment from 0.00 to 0.14 m is dark olive-grey, sandy, silty mud with scattered pebbles (unit 4). Acoustic data show a thin (<0.5 m) layer of unit 4 overlying unit 3.

Core data: cruise 91026 (CSS *Dawson*)

Both piston cores and vibracores were collected during this survey. Three piston cores were collected in Bay of Exploits. Core 008 (water depth 199 m) contains gravelly, sandy clay (0.18–0.29 m), clayey silt (0.01–0.18 m), and a surface layer of silty sand (0.00–0.01 m). The acoustic profile shows that these coarse sediments are part of a thin, surficial layer of postglacial sediments that overlies much thicker glaciomarine deposits. In core 009 (water depth 82 m), the interval from 2.53 m down is dark reddish-grey, sandy, silty clay with angular grit and pebbles and with sandy laminae below 3.30 m. Radiocarbon ages for shell are 11 440 ± 100 BP (3.56 m) and 12 020 ± 100 BP (4.23 m). This interval is interpreted as unit 3. Sediment from 0.00 to 2.53 m consists of locally laminated, dark olive-grey silt with a few pebbles that fines downward to dark grey, silty clay with a few sand lenses between 2.29 and 2.53 m. Radiocarbon ages for shell are 3080 ± 60 BP (0.65 m) and 9680 ± 80 BP (2.30 m). This interval is interpreted as unit 4.

In the third core from Bay of Exploits (core 010, water depth 212 m), the sediment below 0.48 m is silty clay with pebbles and grit and is assigned to unit 3. A shell at 2.06 m is dated at 11 480 ± 100 BP and fragments of a shell at 1.11 m are dated at 10 310 ± 90 BP. The silty clay with a few pebbles from 0.00 to 0.48 m is interpreted as unit 4. Vibracore 041, from a depth of 73 m in Hamilton Sound, contains fine and medium, shelly sand (unit 5). In a second vibracore from Hamilton Sound (core 042, depth 60 m), the interval from 2.70 to 3.29 m is dark grey diamicton with numerous subangular pebbles in a matrix of dark grey, sandy, silty clay (unit 2). Sediment from 1.36 to 2.70 m is light grey, silty clay with subangular pebbles (unit 3). Shell material at 1.59 m has a radiocarbon age of 11 620 ± 120 BP. The surface layer (0.00–1.36 m) is composed of interbedded mud and silty sand, with pebbles and shell fragments scattered throughout (unit 5). Shell material at 0.42 m is dated at 8630 ± 140 BP and bryozoan fragments at 0.51 m are dated at 9290 ± 85 BP.

Core data: cruise 92042 (CSS *Parizeau*)

Piston core 012 was obtained from a depth of 228 m in New Bay. The interval from 8.42 m to the base at 8.76 m is heavily bioturbated, dark grey clay with grit and angular pebbles (unit 3). Sediment from 0.00 to 8.42 m is heavily bioturbated, dark olive-grey, silty clay with local scattered shell fragments and intact bivalves and some lamination from 5.69 to 5.90 m (unit 4). Shell ages are 5980 ± 60 BP (0.63 m), 9210 ± 80 BP (4.45 m), and 11 470 ± 80 BP (7.11 m). Bands of yellowish-white calcite crystals are present at 6.89–6.90 m and 6.92–6.93 m. The core contains scattered pebbles below 7.21 m.

Vibracore 013 was collected (primarily as an equipment test) from a depth of 39 m near Botwood, Bay of Exploits, and is composed of unit 4 sediments throughout: black mud, faintly mottled in places, with scattered worm tubes.

Four vibracores were collected in Deer Cove, Baie Verte. In core 021 (water depth 57 m), the sediment from 0.50 to 1.03 m comprises fine, silty sand, silty clay, and clay and is attributed to unit 4. Shell fragments and a valve at 0.93 m are dated at 8140 ± 70 BP and a valve at 0.98 m is dated at 8720 ± 70 BP. Sediment from 0.00 to 0.50 m is massive, olive-grey, fine-medium sand with scattered shell fragments and pebbles and some organic fragments (unit 5). Wood at 0.47 m is dated at 2200 ± 50 BP. Vibracore 022 (water depth 56 m) contains 0.17 m of shelly, pebbly, medium sand (unit 5). Core 023 (water depth 55 m) from 0.83 m to the base at 1.92 m is probably highly disturbed, possibly as a result of vibracoring or iceberg impact, and contains vertically oriented plumes of silt and pods of sand. Sediment from 0.53 to 0.83 m is olive-grey, fine, silty sand (unit 4). The top of the core from 0.00 to 0.53 m is shelly, well sorted, medium to fine sand (unit 5). Core 024 (water depth 55 m) is entirely (0.00–0.24 m) olive, fine-medium sand with shells and pebbles (unit 5).

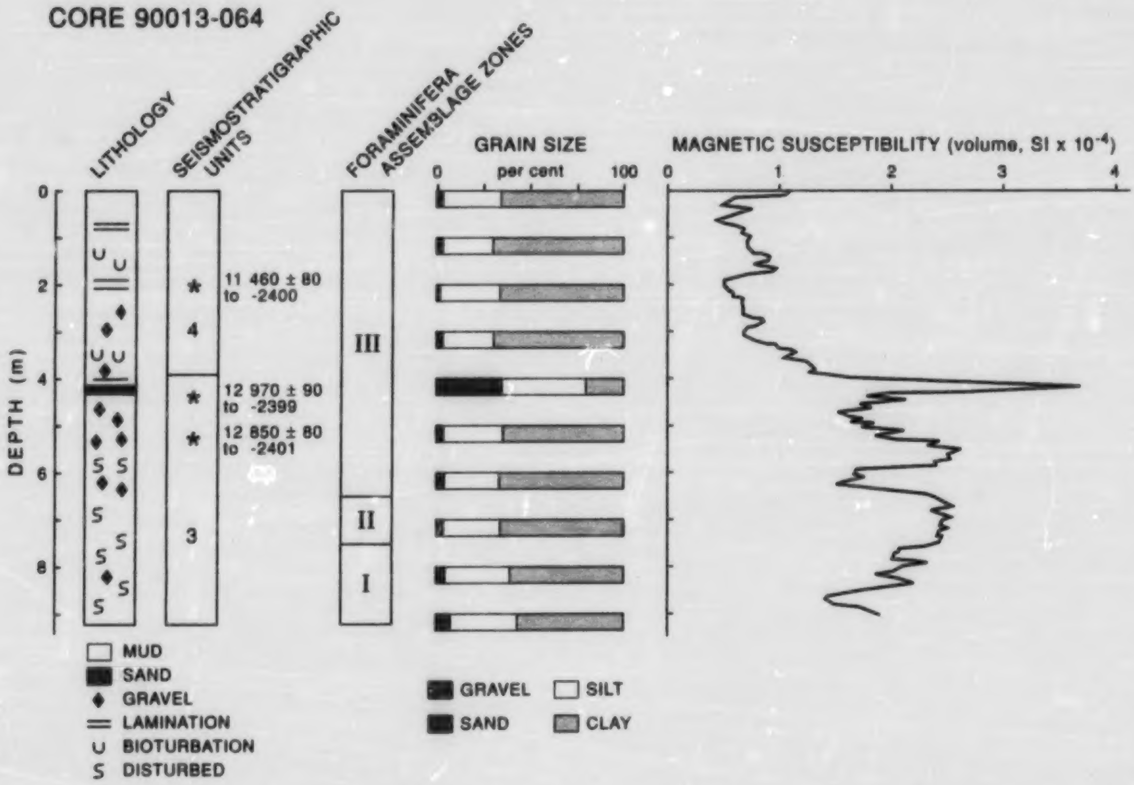


Figure 19. Data from core 90013-064 (grain size, lithology, radiocarbon ages, foraminiferal assemblage zones, magnetic susceptibility).

The target of piston core 032 (Badger Bay, water depth 267 m) was a terrace underlain by acoustically stratified sediment. Material from 0.65 to 8.41 m is grey clay with disseminated grit and angular, fine gravel (unit 3). It is bioturbated in places (e.g. 1.08–1.54 m), layered in part (e.g. 1.54–1.77 m), and massive elsewhere (e.g. 2.11–2.82 m). Concentrated layers of grit and pebbles occur between 2.82 m and 3.08 m. The proportion of gravel increases downward from 3.46 m and is very high from 3.80 to 4.00 m. A few inclusions of grey clay occur at 4.80 m. The interval from 5.48 to 7.20 m is more bioturbated than the intervals above and below. Layers and lenses of well sorted, grey, medium sand are found at 8.04–8.10 m, 7.80–7.88 m, and 7.43–7.45 m. Shell samples from 6.46 m and 2.57 m are dated at 12 420 ± 90 BP and 12 010 ± 90 BP, respectively. The uppermost 0.65 m of this core is locally faintly laminated, olive-grey clay with scattered shell fragments (unit 4).

The target of piston core 033 (Badger Bay, water depth 201 m) was a thin layer, believed to be unit 4, overlying strongly stratified sediments (unit 3). In the trigger-weight core, the interval from 0.16 to 0.82 m is soft, grey, silty clay with an upward-fining sand layer at 0.67–0.69 m. The top 0.16 m is soft, dark, gravelly mud. Below 0.56 m, the piston core consists of medium sand with a vertically oriented central core of grey clay that increases in volume downward. Sediment from 3.42 to 3.62 m is soft, grey, butter-like clay. The top 0.56 m consists of well sorted, medium sand. Because the barrel was bent during coring, the corer is likely to have malfunctioned as a result of encountering

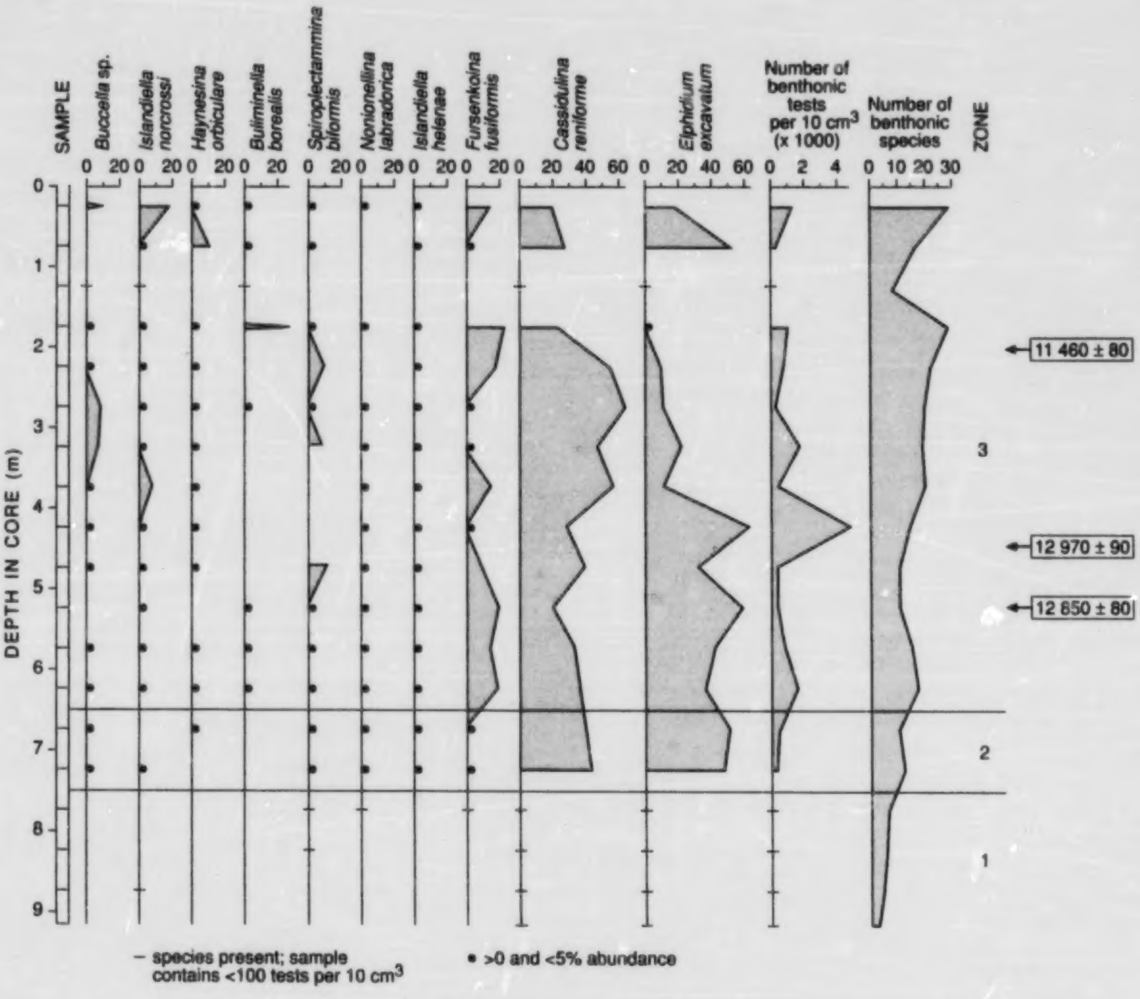


Figure 20. Major benthonic foraminiferal species and zones for core 90013-064. Data analyzed by J. Ceman.

sandy layers in the sediments. The unexpected presence of sand at this relatively great depth may be ascribed to strong bottom currents.

Interpretation of acoustic data

The integration of acoustic data with core and radiocarbon data leads to the following interpretation.

Unit 1, which either forms acoustic basement or has some stratification (on air gun records), is bedrock.

Unit 2, which is acoustically incoherent, is interpreted as glacial diamicton deposited in contact with glacier ice before the deposition of glaciomarine sediments of unit 3. In using the term 'glacial diamicton', we have taken careful note of the conclusions of Syvitski (1991, p. 927) who stated that "...I suggest that the application of genetic names such as glacial diamicton and glacial diamicton tongues should be considered carefully or avoided; these units should be referred to solely as ice-contact sediments." Syvitski noted that acoustically unstratified glacial sediments could include glacial diamicton, ice-loaded glaciomarine sediments, or sand and gravel from a submerged grounding-line fan. In terms of lithology, acoustic attributes, and unit geometry, unit 2 is comparable to the Newfoundland Shelf Drift mapped on the western Grand Banks by Fader et al. (1982), and to unit A (glacial diamicton) mapped in Bonavista Bay by Cumming et al. (1992). Off the east coast of Baie Verte Peninsula, on the flank of Notre Dame Channel, interfingering of the prominent ridge of unit 2 sediments with unit 3 may have resulted from debris-flow deposits that emanated from the ridge (*see* Syvitski, 1991). An alternative interpretation is that the interfingering constitutes a glacial diamicton tongue — a wedge-shaped body that was part of the grounding-line system associated with a floating ice terminus (King et al., 1991).

Facies 1 of unit 3 — moderate- to high-intensity, continuous, coherent reflections highly conformable to the underlying terrain, with scattered point-source reflections — is interpreted as a glaciomarine, hemipelagic deposit formed by the accumulation of sediment transported by glacial meltwater plumes. In some areas, for example the north side of Baie Verte Peninsula, it has been furrowed by icebergs to form an iceberg turbate similar in acoustic appearance to unit 2. Facies 2 of unit 3 — acoustically transparent intervals up to 20 m thick, interleaved with ponded, stratified sediments — is interpreted as glaciomarine sediment deposited by turbidity currents, debris flows, and meltwater plumes close to the margin of Late Wisconsinan glacier ice. Facies 3, similar in acoustic appearance to facies 2, but contorted and containing slip planes, is interpreted as glaciomarine sediment deposited by turbidity currents, debris flows, and meltwater plumes close to the former ice margin and subject to postdepositional deformation, possibly during a period of rapidly falling relative sea level when glacier ice remained close to the coast.

Unit 4, which has low-intensity, ponded to conformable, internal reflections towards its base, but tends towards acoustic transparency higher up, is interpreted as postglacial mud in which the proportion of ice-rafted debris is highest near the base. In an early phase, sediment was contributed to this unit not only by ice rafting, but also by distant meltwater plumes from fiord glaciers. In a later (and much longer) phase, unit 4 formed as a result of reworking of units 2 and 3 by waves and currents. Where sediments similar to unit 4 occur in coastal basins elsewhere in Newfoundland (e.g. St. George's Bay, Placentia Bay), they commonly contain shallow gas that masks acoustic reflections at depths greater than 4–5 m below the seabed; this is not the case in the study area.

Unit 5 is interpreted as a postglacial, littoral and nearshore deposit that occurs above the present wave base. It formed as a result of reworking of older units by waves and currents.

Distribution of surficial units

Figure 1 shows the distribution of surficial units in Notre Dame Bay. Unit 1 (bedrock) occurs in a shallow coastal fringe characterized by scattered bedrock outcrops with discontinuous veneers of gravel, sand, or mud. Thicker pockets of sediment occur between bedrock highs. The largest bedrock area occurs off the northeast coast, seaward of a zone of postglacial sand and gravel. Unit 2 (glacial diamicton) occupies large tracts of the shelf, particularly away from coastal areas. Most of unit 2 has a rugged surface, with relief of about 5 m, partly because of iceberg furrowing. Unit 3 (stratified, glaciomarine mud) typically outcrops as a narrow band along the flanks of basins, with glacial diamicton upslope and postglacial mud downslope. More extensive areas of unit 3 are found north of the fiords and north of Baie Verte Peninsula. Unit 4 (postglacial mud) occurs most extensively in White Bay and the basin to the north, in Notre Dame Basin, and in several other basins on the shelf, with lesser deposits in bays and fiords. Unit 5 (postglacial sand and gravel) is found throughout the region in shallow water close to the coast, as isolated pockets, shore-parallel bands, or aprons extending from deep water to beaches. The most extensive occurrence is a large area off the northeast coast.

GLACIATION AND POSTGLACIAL SEA LEVELS

Maximum extent of ice and directions of ice movement

The regions of Newfoundland bordering the northeast coast were covered by glacier ice that moved outward from the centre of the island during the Late Wisconsinan substage (Grant, 1977, 1989a, 1994). The maximum extent of Late Wisconsinan ice off northeastern Newfoundland remains a matter for debate. Grant (1994) reviewed an extensive body of data on the glaciation of central and western Newfoundland and stated that offshore work (including Slatt, 1974; Haworth et al., 1976a, b; Piper et al., 1978; Dale and Haworth, 1979; Mudie and Guilbault, 1982; Scott et al. 1984) had yielded evidence for "limited Late Wisconsinan glacier extent." Drawing on this body of research and on his own onshore data, he concluded that the ice of an early maximum glaciation barely extended beyond the Grey Islands and about 40 km east of the Horse Islands. The limit of the Late Wisconsinan advance phase lay west of the Grey Islands and between the Horse Islands and the coast of Baie Verte Peninsula. However, much of the early work reviewed by Grant was not backed up by marine geological survey data or was based on a limited amount of such data.

The concept of limited Late Wisconsinan ice on the shelf was supported by Dyke and Prest (1987) who located a 13.0–18.0 ka ice margin north of Baie Verte Peninsula that crosses the peninsula near La Scie, extends east-west across Notre Dame Bay, turns southeastward across the mouth of Gander Bay to Carmanville, and continues just inland from The Straight Shore.

St. Croix and Taylor (1991) integrated the work of Jenness (1960), Prest (1970), Grant (1977, 1989a, b), and others with the results of their own striation mapping in the Notre Dame Bay area. They recognized the following events: 1) coalescent ice caps on Northern Peninsula and in central Newfoundland; 2) separation of these ice caps so that central Newfoundland ice flowed north past the present coast of Notre Dame Bay; 3) as deglaciation proceeded, splitting of the central Newfoundland ice cap into independent ice caps; and 4) final decay of the ice cap, with minor centres that may have readvanced, possibly during the Younger Dryas interval. They argued that the predominant east-southeast orientation of their first ice-flow event could have been due to deflection of central Newfoundland ice by ice flowing southeast from Northern Peninsula.

For several reasons, these concepts are difficult to reconcile with the offshore evidence. Firstly, the present surveys have revealed no evidence (e.g. moraines) for some of the proposed margins, for example in the region between Baie Verte Peninsula and the Horse Islands. Secondly, it can be argued that ice covered the entire study area at least once during the Quaternary. Piper et al. (1990) stated that glacial diamicton occurs as far as the shelf break. Evidence of this was provided by Dale and Haworth (1979) who mapped a seismic unit interpreted as glacial diamicton throughout the region to the limits of their study area (latitude 52°N, longitude 53°W). Whether or not all of this glacial diamicton was deposited by Late Wisconsinan ice is unknown, although Piper et al. (1990, p. 536) stated that "...there appears to have been grounded ice on the inner part of the Northeast Newfoundland Shelf in the Late Wisconsinan."

Relatively thick (20–30 m) deposits of unit 2 (glacial diamicton) occur on either flank of Notre Dame Channel and unit 2 underlies the glaciomarine and postglacial sediments in the channel. On the south flank, successive ridges of unit 2 occur just north of Bay of Exploits sill in water depths of 220 m, 240 m, and 265 m (this last ridge is 25 m thick). On the north flank, deposits up to 30 m thick are found above a depth of 240 m, due east of Baie Verte Peninsula. They extend southwest on the basin flank, forming a ridge (*see* Fig. 1, 7) that runs parallel to the northeast coast of Baie Verte Peninsula. An analysis of an assemblage of gravel clasts from IKU grab sample 90013-035 (D.G.E. Liverman, pers. comm., 1991), collected where the surface of the ridge is exposed at the seabed, might suggest that they were deposited by ice rafted from Northern Peninsula and Labrador at the end of the last glaciation. Considering the location and orientation of the ridge, we favour an alternative hypothesis, namely that the gravel was transported by grounded ice from the northwest, across White Bay and Cape St. John.

The glacial diamicton deposits on the north and south flanks of Notre Dame Channel could be interpreted as indicating positions of former ice-grounding lines or margins. We have no evidence for the age of such ice-grounding lines or margins, although the fact that the unit 2 deposits have a relatively thin drape of glaciomarine sediments overlain by postglacial mud tends to suggest that they are Late Wisconsinan. This is consistent with the 'first ice-flow event' described by St. Croix and Taylor (1991), in which ice masses from the south and northwest were confluent in Notre Dame Bay. It is also consistent with some of the restricted Late Wisconsinan ice margins described by others (e.g. Dyke and Prest, 1987), if those ice margins are extended seaward somewhat and if ice from the northwest covered the extreme northeast tip of Baie Verte Peninsula.

Deglaciation

Evidence for the absence or withdrawal of grounded ice from Notre Dame Bay is derived from radiocarbon ages of samples from stratified sediments offshore. The earliest ages come from ice-proximal sediments contained in core 78023-20, collected about 50 km east-northeast of the Horse Islands. Mudie and Guilbault (1982) published total organic carbon ages of 21 980 ± 1135 BP and 25 490 +1570/-1310 BP (at 8.61–8.69 and 8.90–9.12 m respectively); they reasoned that these ages were too old and should be corrected to about 16 980 and 18 000–19 000 BP respectively. However, Scott et al. (1989) published an AMS age of 21 800 ± 500 BP on picked foraminifera from 6.97–6.99 m in this core; this age must be regarded as the most reliable of the three and, as the authors pointed out, it is one of the oldest credible ages from the Atlantic margin.

A few kilometres offshore from the eastern side of Baie Verte Peninsula, about 80 km southwest of the site of core 78023-020, the retreat of grounded ice is constrained by dating of samples from piston cores that intersected a sequence comprising (from bottom to top) glacial diamicton, glaciomarine, sandy, gravelly mud, and postglacial mud. In core 90013-051, shell in glaciomarine clay at 4.78 m is dated at 12 440 ± 240 BP (TO-3155) and shell samples at 4.45 and 5.22 m in core 90013-064 are dated at 12 970 ± 90 BP (TO-2399) and 12 850 ± 80 BP (TO-2401) respectively. Thus, open-water conditions began before about 13 ka.

Ice retreated landward from the outer coast of Notre Dame Bay as demonstrated by evidence from Leading Tickles, which is situated on a peninsula between Seal Bay and New Bay. There, pioneer herb-shrub vegetation was established by about 13.5 ka (Macpherson and Anderson, 1985). Ice was absent from Fogo Island by 11 000 ± 260 BP (GSC-3973), when basal lake sediment was being deposited at Freemans Pond, although in this case, deglaciation probably occurred considerably earlier. Cumming et al. (1992) argued that ice had retreated inland from the present coast of nearby Bonavista Bay by 12 790 BP.

A relatively large body of evidence shows that the Late Wisconsinan glaciers retreated to the heads of the fiords and remained there for several thousand years. The discharge of meltwater and sediment at the ice front resulted in the formation of marine-delta complexes and thick deposits of stratified, glaciomarine sediments in the fiords. The data pertaining to this phase are discussed below.

White Bay and Green Bay

Grant (1994) described the retreat of ice on the Great Northern Peninsula. He stated that "When the ice caps retreated inland of the marine limit they stabilized, building moraines and deltas;..." (p. 50). Ages from the deltaic environments in White Bay are relatively young compared with those from elsewhere in the study area. Grant (1989b) published an age of 11 200 ± 100 BP (GSC-4247) for shell at +25 m in Jackson's Arm. This was thought to indicate a recessional halt of Long Range ice, perhaps correlated with the Younger Dryas cool period (*see* commentary *in* Blake, 1988). Similarly, an age of 10 200 ± 100 BP (GSC-4023) for shell at +27 m near Sops Arm was also thought to be related to a Younger Dryas ice-marginal stand (Grant, 1989b). Farther east, in Green Bay, raised marine deltas are found in the Kings Point area and in Middle Arm (Grant, 1989b). Radiocarbon ages in this region are 11 950 ± 170 BP (GSC-75) for shell at 11 m and 11 880 ± 190 BP (GSC-87) for shell at 12 m. An age of 11 700 ± 110 BP (GSC-4311) for shell at 13 m was thought by Grant (*in* Blake, 1988) to be related to an important glacier stillstand. Liverman and Scott (1990) reviewed data from the King's Point map sheet (NTS 12H/9) and concluded that ice stagnated at the head of Green Bay from 12 000 to 11 700 BP and that the marine limit there was +75 m.

Baie Verte Peninsula

Although large marine deltas did not form on this peninsula, there is nevertheless evidence for the presence of ice margins. Shells in stratified silt at approximately +72 m at Deer Cove Pond are dated at 12 400 ± 110 BP (GSC-4700; *see* commentary by Grant *in* McNeely and McCuaig, 1991). The silt was deposited during early marine submergence and was thought to have been overridden by an ice advance, possibly correlated with the regional climatic reversal of 10–11 ka. Grant thought this age difficult (but not impossible) to reconcile with that of postglacial lake sediment at nearby Compass Pond (11 700 ± 180 BP; GSC-3891, Blake 1986).

Halls Bay

Raised marine delta deposits at elevations up to +75 m that are found along the coast of inner Halls Bay (Tucker, 1974) contain shells dated at 12 000 ± 220 BP (GSC-1733) and 11 000 ± 190 BP (GSC-2085). More recently published radiocarbon dates include ages of 11 700 ± 110 BP (GSC-5171) and 11 300 ± 120 BP (GSC-5140) for shells, and 11 340 ± 150 BP (TO-2306) and 12 470 ± 380 BP (TO-2305) for plant and shell fragments (Scott and Liverman, 1991; Scott et al., 1991). These authors concluded that the highest glaciomarine deltas predated 12.47 ka and that successive terraces and ice-contact deltas formed at lower elevations as relative sea level dropped. Just north of Halls Bay, shell fragments contained in glaciomarine diamicton near the Little Bay mine are dated at 12 200 ± 110 BP (GSC-5898; D.G.E. Liverman, pers. comm., 1995).

The age of the final phase of glaciomarine sedimentation in Halls Bay, as determined from offshore samples, is in good agreement with the age determined from the onshore samples noted above. Shell from 4.00 m depth in core 90013-063, collected just south of Springdale, was dated at 11 330 ± 130 BP (TO-3170). The core penetrated the upper part of deformed, well stratified, glaciomarine sediments that contain small-scale listric riders. The sediments were probably deposited by meltwater plumes emanating from glaciomarine deltas near Springdale and at the head of the bay. By that time, relative sea level had fallen considerably from the maximum, perhaps to between +40 and +50 m. The sample from glaciomarine sediments intersected by core 90035-183 in the Sunday Cove Island area dates the late phase of ice-distal sedimentation in outer Halls Bay at 11 600 ± 80 BP (TO-2395).

Badger Bay, New Bay, Bay of Exploits

In Badger Bay, core 92042-032 contained 0.65 m of (postglacial) olive-grey clay overlying glaciomarine mud with grit and angular pebbles. Radiocarbon dating of the glaciomarine mud unit gives ages of 12 010 ± 90 BP (2.57 m) and 12 420 ± 90 BP (6.46 m). In nearby New Bay, bivalve samples from postglacial mud at 0.63, 4.45, and 7.11 m in core 92042-012 are dated at 5980 ± 60 BP, 9210 ± 80 BP, and 11 470 ± 80 BP respectively. These ages postdate glaciomarine sedimentation recorded at the bottom of the core, from 8.42–8.76 m (butter-like grey clay with grit and angular pebbles). New Bay is a small fiord and, unlike Halls Bay, probably did not contain a stable ice margin.

Evidence from Bay of Exploits (Fig. 10) shows that the retreating ice halted several times in the fiord. Firstly, the ice formed a moraine 40 m thick just east of Indian Cove Island; the moraine was subsequently covered by stratified, glaciomarine sediments (unit 3). After later southward retreat, the ice formed a prominent moraine that extends across the bay from Point of Bay to Porterville (the Porterville Moraine). Deposits of ice-contact, stratified drift with ice-push contortions occur onshore at that location (D.R. Grant, pers. comm., 1993). After further southward recession, the ice margin may have been stabilized for a time by the bedrock ridge that extends across the bay at Phillips Head.

Radiocarbon dating of sediments in the bay provides an estimate of the age of the moraines. In core 91026-010, a shell in glaciomarine clay at 2.06 m is dated at 11 480 ± 100 BP (Beta-51674/ETH-9469) and stratigraphically postdates the Indian Cove Island and Porterville moraines. In core 91026-009, shell fragments in glaciomarine sediments at 4.23 m are dated at 12 020 ± 100 BP (Beta-51672/ETH-9467) and postdate the moraines at Indian Cove Island, Porterville, and Phillips Head.

With further ice retreat, the sea invaded the Exploits River valley beyond the present coast, as demonstrated by an age of 11 600 ± 210 BP (GSC-2134) for barnacles from a site on the banks of the Exploits River (D.R. Grant *in* Blake, 1983). An age of 11 400 ± 100 BP (GSC-3687) for shells at Bishop's Falls was interpreted by D.G. Vanderveer (*in* Blake, 1983) as showing that the postglacial marine incursion had reached 10–15 km from the head of Bay of Exploits by 11.4 ka.

Hamilton Sound

A shell found at 1.59 m in core 91026-042 (water depth 57 m) from Hamilton Sound is dated at 11 620 ± 120 BP (Beta-51677). Paleoecological analyses have not been performed on samples from this core, but the lithology of the dated sediment (clayey silt with angular grit and pebbles) and acoustic signature (continuous, moderate to strong intensity, coherent, internal reflections, and a draped style) are strongly suggestive of glaciomarine sedimentation, probably from meltwater plumes emanating from ice at the heads of bays in the region.

The 12 ka ice margin

It would be useful to show on a map successive ice-margin positions for this region, but we have not done so for several reasons. Mapping ice margins from as late as 11 ka involves the interpretation of significant amounts of onshore data, a task that is beyond the scope of the MDA program. Mapping ice limits older than 13 ka is difficult because we have not located and dated ice-margin deposits (e.g. moraines) offshore. The 12 ka margin (Fig. 21) is arguably the least difficult to locate because, as noted above, published radiocarbon dates indicate that the ice margin was close to the present coast at that time and dated shell samples from cores offshore indicate both the absence of grounded ice and the existence of open-water conditions. The margin shown here is based on the work of Dyke and Prest (1987), on interpretations of radiocarbon data published by Grant (1975, 1977, 1980, 1989a, b, 1994) and others, and on radiocarbon data collected offshore as part of the MDA program. The ice margin shown for the Springdale–Halls Bay region is based on that mapped by Scott et al. (1991).

Postglacial changes in relative sea level

Long-term, relative sea-level changes

Relative sea level was higher than present about 12 ka when glacier ice was at, or close to, the coasts of the study area. The marine limit in coastal regions (Fig. 22a) is approximately 100 m in White Bay (Grant, 1989a), declining to 43 m near Hamilton Sound (Grant, 1980). Although this pattern may be incorrect in detail — for example, Catto (1993) reported a limit at 67 m in the Hamilton Sound area and Grant (1994) published a map showing slightly differing elevations in the western part of the study area —, its general outlines are supported by various authors (*see* Jenness, 1960; Wightman and Cooke, 1978; Rogerson, 1982; Scott and Liverman, 1991).

Relative sea level dropped rapidly from the marine limit as a result of elastic rebound of the crust, as shown by terraces and deltas at successively lower elevations (*see* data from Halls Bay described briefly above and reported by Tucker 1974, Scott and Liverman, 1991, Scott et al., 1991). Shaw and Forbes (1995) show that across much of southern Newfoundland, postglacial relative sea level dropped below the present level (Fig. 22b). The postglacial minimum was

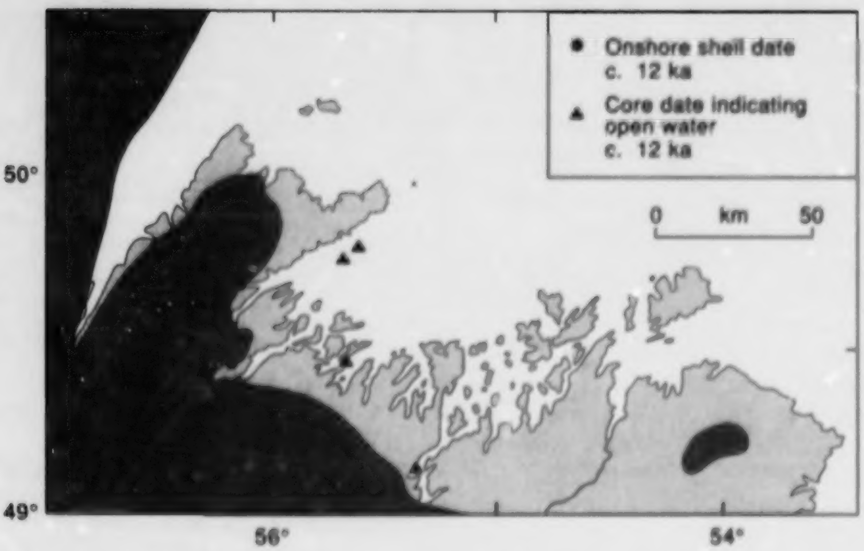
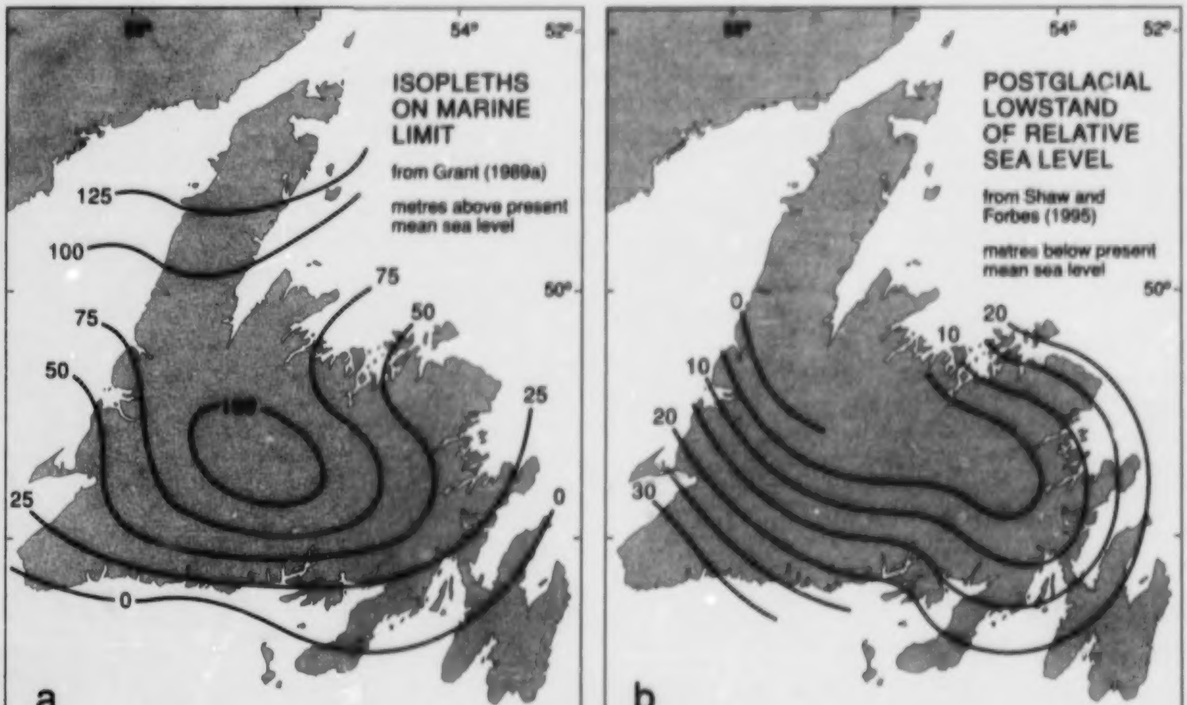


Figure 21. *Hypothetical ice margin at 12 ka, based on published radiocarbon dates, map by Dyke and Prest (1987), and map of the Springdale–Halls Bay region by Scott et al. (1991). The radiocarbon dates shown here are mainly from onshore shells and indicate marine conditions at or slightly after 12 ka. The map also shows the sites of offshore cores containing dated shells that indicate open water at 12 ka. However, numerous other cores not shown here provide radiocarbon dates in the 11–12 ka range from samples at the top of thick deposits of marine sediments and indirectly show open water at this time. Marine overlap at this time was at about +60 m in White Bay and +10 m in Hamilton Sound.*



diachronous and its depth varied spatially (*see* Forbes et al., 1993), reaching 30 m below present sea level (the lowstand may have been deeper than this in extreme southwestern and southeastern Newfoundland). Rivers became incised into glacial deposits and graded to the lowered sea levels, forming deltas that were subsequently submerged.

Shaw and Edwardson (1994) argued that the postglacial lowstand of relative sea level in Hamilton Sound (eastern part of the study area) was at -17 m, on the basis of the occurrence of wave-cut terraces at -17 to -20 m and drumlin crests at -19 m that have not been modified by wave action. The lowstand was thought to have occurred before 8.6 ka. Evidence from onshore (Shaw and Forbes, 1990a) shows that relative sea level had risen close to the present level in this area by 3.5 ka.

Deltas that formed during the postglacial sea-level lowstand and that are presently submerged occur at only two locations in Notre Dame Bay. At the mouth of the Exploits River, extensive subtidal shallows (Canadian Hydrographic Service, 1981b) terminate opposite Botwood in a relatively steep slope with a crest at 5.5 m below chart datum. Mean sea level is 0.6 m above chart datum, so the submerged delta of Exploits River is 6.1 m below mean sea level. If the former delta prograded to the low-water mark, then the relative sea-level lowstand was at -5.5 m. A less convincing terrace off West Arm Brook, in New Bay, suggests a relative sea-level lowstand at -3.7 m.

There are no signs of submerged terraces offshore from modern deltas in the western part of the study area, for example at the head of Halls Bay and in Baie Verte. In Sops Arm (White Bay), Main Brook is deeply incised into glaciofluvial deposits and has formed a delta at the coast. The subaqueous delta dips steeply to about -68 m, with a slope of 19°. Survey lines were not sufficiently close to shore to detect the prodelta sediments. Nearby, at the head of White Bay, the Hampden River also has a delta, but there is no evidence of a submerged delta terrace. The absence of submerged terraces offshore from modern deltas could be because relative sea level never fell below the present level. Alternatively, it could be argued that relative sea level did drop below the present level and that the deltas aggraded sufficiently to maintain their positions during the later transgression.

The geomorphological evidence suggests that a postglacial lowstand below present sea level occurred only in the east of Notre Dame Bay. The postglacial sea-level minimum in Notre Dame Bay probably decreases westward, from -20 m just east of Hamilton Sound to 0 m on Baie Verte Peninsula. Suggested (very approximate) relative sea-level curves for three parts of the study area, based on data from sources cited in the text, are shown in Figure 23. These simplified curves omit the probable stillstand at 11–10 ka and the possible fluctuation at 3–1 ka suggested by Grant (1994).

Figure 22.

a) Postglacial marine limit in Newfoundland.
b) Postglacial relative sea-level lowstand.

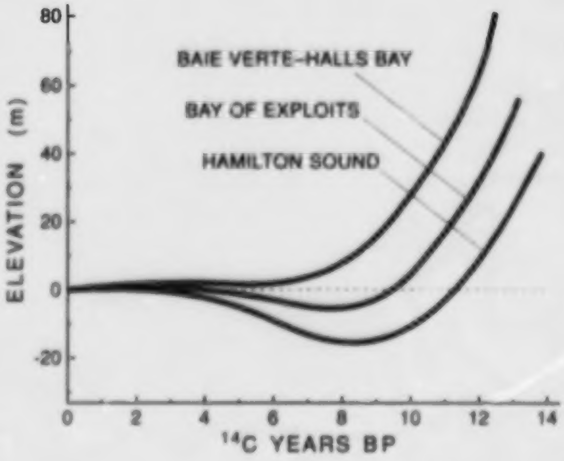


Figure 23. *Hypothetical relative sea-level curves for three regions in the study area, based on data from sources cited in the text. Liverman (1994) has argued that relative sea level dropped below the present level over all of the island except the tip of Northern Peninsula, in which case the suggested curve for the Baie Verte–Halls Bay area would dip below present sea level.*

Although we discovered no evidence that postglacial relative sea level fell below present sea level in the western part of the study area, some authors have argued that it did. Liverman (1994) thought that the present database of radiocarbon dates on shell material collected onshore is consistent with a postglacial lowstand below present sea level, not only in Notre Dame Bay, but even farther north, along Great Northern Peninsula. Furthermore, Grant (1994) argued that relative sea level in the Port Saunders map area (west coast of Great Northern Peninsula) dropped from marine limit to a stillstand between 11 and 10 ka, before falling even more; the relative sea-level curve from the southern part of his study area showed a fall of about 10 m below present sea level at approximately 5.5 ka.

Recent relative sea-level change based on tide-gauge data

Tide gauges installed in eastern Canada at the end of the nineteenth century (Shaw and Forbes, 1990b) provide evidence of recent trends in mean sea level in Atlantic Canada. Unfortunately, no gauges were placed in the Notre Dame

Bay area. The nearest station for which data are available, St. John's, showed a rise of +19.3 cm/century according to G. Carrera, P. Vaníček, and M.R. Craymer (unpub. rept., 1990) and of +23.9 cm/century according to Shaw and Forbes (1990b). It is difficult to assign a rate for Notre Dame Bay. However, it is worth noting that the Harrington Harbour (southern Labrador) record shows a rise of only +1.3 cm/century (G. Carrera, P. Vaníček, and M.R. Craymer, unpub. rept., 1990), a difference that may be attributed to the effects of continuing viscous crustal rebound in that region. The free-air gravity anomaly slopes northwest (*see* Grant, 1989a, Fig. 5.14, and Andrews and Peltier, 1989, Fig. 8.18) and it seems reasonable to conclude that relative sea level is rising across Notre Dame Bay at rates between those of St. John's and Harrington Harbour, perhaps between 5 and 15 cm/century.

COASTAL GEOMORPHOLOGY AND SEDIMENTS

Shoreline classification

Previous work in the area includes shore-zone mapping by the Lands Directorate of Environment Canada (Hiscock and Maloney, 1983) and complete aerial video coverage obtained for Petro-Canada by Woodward Clyde Consultants (E.H. Owens and E.R. White, unpub. rept., 1982). The latter study included 1:125 000 scale mapping for oil-spill sensitivity and contingency planning. The same video imagery was used in the present study to map a wide variety of shore-zone features at a scale of 1:50 000.

The shores of the study area are dominated by bedrock, with very limited development of depositional landforms, in part reflecting a restricted sediment supply to the modern coast. Beaches occupy only 16 per cent of approximately 3150 km of shoreline in the region. Erosional exposures of unlithified sediments in backshore cliffs are extremely rare (0.9 per cent of total shore length) and are restricted primarily to inner-fiord locations in Notre Dame Bay. Wave exposure varies from very protected inner-bay settings to large sections of coast that are fully open to the Labrador Sea and North Atlantic Ocean.

Following the method used by Fricker and Forbes (1988), we divided the study area into ten regions and subregions (Fig. 24) for detailed mapping and statistical analysis. The boundaries are based on varying geographic features, geological provinces, general exposure, and coastal geomorphology. The list of mapped features is given in Table 2, which also shows the two-letter codes used in the analyses. Table 3 shows the distribution of shore features by region and subregion as a percentage of region/subregion length (%) and as raw shore length (km).

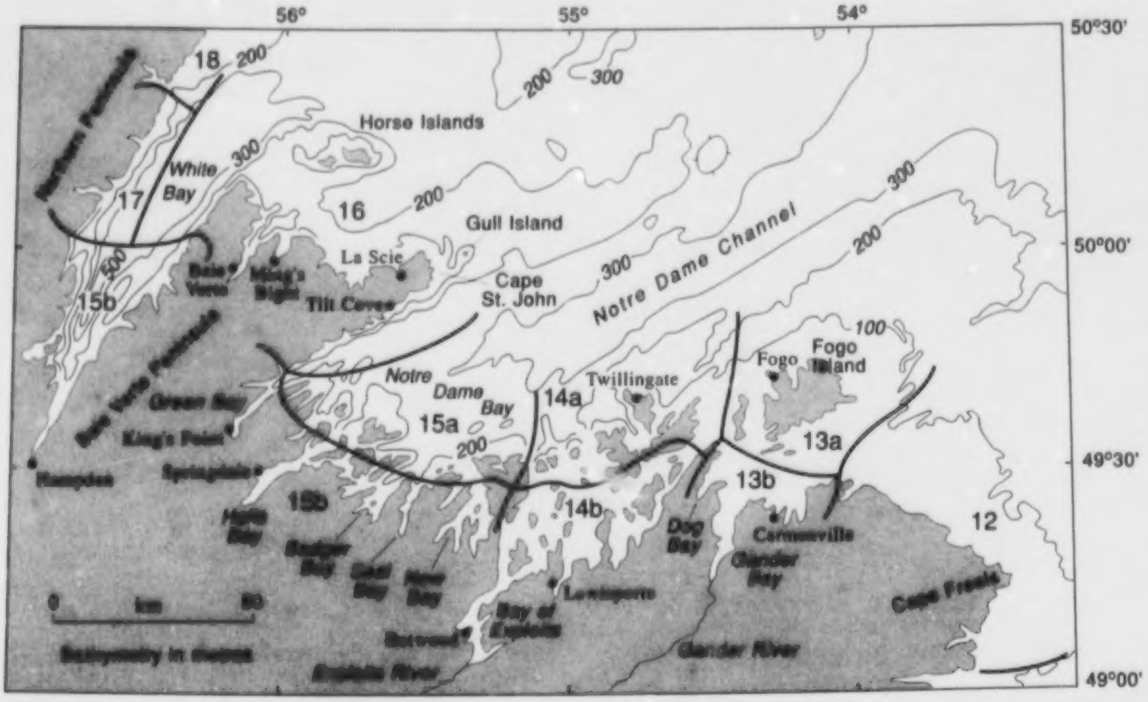


Figure 24. Map of the study area showing the ten coastal regions referred to in the text.

Table 2. Shore features mapped for this study (with two-letter codes).

RO	rock outcrop (undifferentiated)
RC	rock cliff (rock face over 45° and over 2 m high)
RR	rock ramp (wave-washed rock face under 45° and over 2 m high)
RP	rock platform (intertidal or shallow subtidal terrace)
CO	colluvium (talus and talus cone)
BL	cliff-fall block or boulder accumulation
UC	unconsolidated cliff (eroded bluff over 2 m high)
BP	boulder platform (boulder-strewn nearshore terrace)
BB	boulder barricade
BF	boulder flat (boulder-strewn tidal flat)
SF	sand and/or mud flat (intertidal and shallow subtidal flat)
MA	marsh (organic intertidal and supratidal flat)
GB	gravel-dominated beach
SB	sand-dominated beach
SD	sand dune
FD	fluvial delta
AT	artificial shoreline

Because of their relevance to the study of placer gold potential in the region, all beaches at least 20 m long were located and their lengths estimated to the nearest 20 m. Beaches were classified as predominantly sand or predominantly gravel. Beaches recorded as predominantly gravel consist of material with a wide range of size classes from boulders to sandy gravel, with sand representing a significant proportion of the sediment in many cases.

Coast types and regional overview

Six broad coast types are recognized in the study area. Their distribution is shown in Figure 1 and is given below.

Type 1: Exposed, rock-dominated, low-relief coast with extensive sandy beaches and dunes

Type 1 coasts (Fig. 25, 26) are restricted to a part of region 12 (Fig. 24) between Cape Freels and Ragged Harbour, where sand has accumulated in numerous shallow embayments landward of a broad, shallow, transgressed shelf characterized by granite outcrops and wave-rippled gravel (Shaw and Forbes, 1990a). Extensive sandy beaches, barriers, and tombolos are found on several points along this coast, including Cape Freels, Lumsden, Deadman's Bay, Shalloway Brook, and Man Point. This is the only part of

Table 3. Distribution of shore features by region and subregion as a percentage of region/subregion length (%) and as raw length (km). Note that percentages may exceed 100% because many features occur together and all rock features are also included in the rock outcrop total. '?' refers to unmapped shoreline (not visible in the video record). *See* Table 2 for explanation of feature codes.

	length	RO	RC	RR	RP	CO	BL	UC	BP	BB	BF	SF	MA	GB	SB	SD	FD	AT	?
length (per cent)																			
12		73.0	0.5	0.4	13.4	0.0	0.0	0.2	6.9	0.0	10.1	2.7	2.4	9.4	13.7	7.8	0.0	1.4	0
13a		95.8	1.8	4.6	16.0	0.0	0.0	0.0	1.0	0.0	4.9	0.0	0.0	7.8	0.3	0.3	0.0	1.2	0
13b		47.2	1.4	0.0	25.2	0.0	1.5	0.0	26.5	0.4	33.0	0.1	1.0	24.7	0.7	0.0	0.1	0.7	0
14a		89.6	12.9	0.1	5.1	0.0	0.1	0.1	0.6	0.0	1.6	0.3	0.1	7.6	0.0	0.0	0.0	1.2	7
14b		65.7	2.5	0.2	16.2	0.1	0.0	0.5	27.2	2.2	11.5	0.3	1.8	23.8	0.2	0.0	0.1	1.4	0
15a		84.9	33.1	0.0	6.4	0.3	1.5	0.3	0.3	0.1	0.6	0.0	0.2	12.6	0.1	0.0	0.0	1.2	5
15b		67.8	12.2	0.0	3.2	0.1	1.3	3.9	2.4	0.9	3.5	1.2	0.9	23.4	2.5	0.0	0.8	1.6	6
16		90.6	41.2	1.2	6.2	0.4	3.9	0.0	0.2	0.1	0.4	0.4	0.1	7.0	0.3	0.0	0.5	1.6	0
17		82.6	28.0	0.0	7.2	0.4	0.1	0.6	0.0	0.1	1.1	3.1	0.0	13.7	1.4	0.2	0.9	0.9	5
18		96.1	26.2	6.4	0.0	1.9	0.6	0.0	0.0	0.0	0.6	0.0	0.0	3.9	0.2	0.0	0.4	0.5	4
length (km)																			
12	227.2	165.9	1.1	1.0	30.4	0.0	0.0	0.5	15.6	0.0	23.0	6.1	5.5	21.3	31.1	17.8	0.0	3.2	1
13a	202.5	193.9	3.6	9.3	32.4	0.0	0.0	0.0	2.0	0.0	9.9	0.0	0.0	15.7	0.6	0.6	0.0	2.4	0
13b	193.9	91.5	2.7	0.0	48.9	0.0	1.0	0.0	51.3	0.8	63.9	0.2	1.9	47.9	1.4	0.0	0.2	1.3	0
14a	370.4	331.9	47.8	0.4	18.9	0.0	0.4	0.2	2.2	0.0	6.0	1.0	0.2	28.3	0.0	0.0	0.0	4.3	25
14b	386.4	254.0	9.6	0.6	62.4	0.2	0.0	1.8	105.1	8.5	44.4	1.2	6.9	92.0	0.7	0.0	0.2	5.6	1
15a	479.5	407.2	158.5	0.0	30.8	1.2	2.6	1.3	1.6	0.6	3.0	0.0	0.9	60.3	0.5	0.1	0.1	5.9	26
15b	564.2	382.3	68.7	0.0	18.1	0.7	7.1	22.2	13.8	4.8	19.6	7.0	4.9	132.3	14.2	0.0	4.7	9.3	33
16	308.4	279.4	127.0	3.6	19.0	1.2	11.9	0.0	0.6	0.2	1.1	1.3	0.3	21.7	0.9	0.0	1.4	5.0	0
17	271.1	224.0	76.0	0.0	19.5	1.0	0.4	1.5	0.0	0.3	2.9	8.3	0.0	37.2	3.7	0.5	2.4	2.5	15
18	148.7	142.9	39.0	9.5	0.0	1.4	0.9	0.0	0.0	0.0	0.9	0.0	0.0	5.9	0.3	0.0	0.6	0.7	6

the study area with well developed coastal dunes, which cover almost 18 km, or 7.8 per cent of the coast in region 12, but less than 1.5 km in all other regions combined.

Type 2: Highly exposed, rock-dominated, low- to high-relief coast with rock cliffs, wave-washed rock ramps, and limited beach development

Type 2 coasts (Fig. 27, 28) dominate regions 13 to 18 (Fig. 24). Bold rock cliffs rising to 50 m and higher are present in several areas, including Bacalhao, North Twillingate, and Black islands, North Head (at the western entrance to Ship Run in Bay of Exploits), Cape St. John, and the outer coast of Baie Verte Peninsula west to Ming's Bight, the outer coast of White Bay on the west side of the peninsula, and across the bay from Coney Head north to Great Harbour Deep and beyond. Wave-washed rock ramps are present in a number of areas, including Cape Fogo and the north shore of Fogo Island (between Round Head and Joe Batt's Arm), at Grappling, White, and Partridge points along the northern coast of Baie Verte Peninsula, and in region 18 north of White Bay from near Great Cat Arm here and there to Pigeon Cove (north of Great Harbour Deep). Estimates from the video imagery suggest runup to 15 m at Grappling Point and to 22 m south of Little Harbour Deep. Beaches on type 2 coasts are short, narrow, and thin, composed of coarse-grained sediment, and typically occur in pockets at the base of cliffs.

Type 3: Semiexposed, rock-dominated, island and outer-fiord coast with rock platforms, rock cliffs, and limited beach development

Type 3 coasts (Fig. 29, 30) include a variety of semiexposed, rocky shorelines in outer-fiord settings and other partly protected locations. Examples include the west side

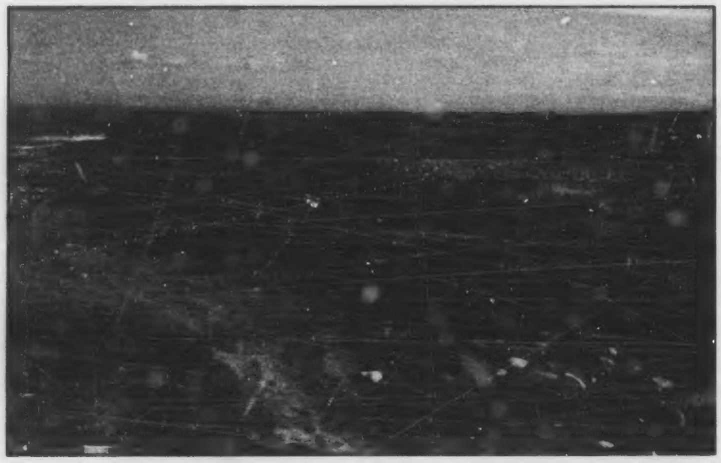


Figure 25.

Type 1 coast at Man Point, a sandy foreland on The Straight Shore. The coast in this region comprises low granite headlands, sandy beaches, lagoons, and coastal dunes. This view shows overwash material spread across low coastal dunes. The dunes form a veneer several tens of centimetres thick over woody, freshwater peat (visible in the left foreground) that formed on top of dune ridges that are 3000 years old (see Shaw and Forbes, 1990a). Photograph by J. Shaw, 17 September 1987. GSC 1998-055A

Figure 26.

Type 1 coast at Cape Freels. These coastal dunes have been disturbed by human activity. They contain an extensive organic horizon with a radiocarbon age of 1.6 ka (see Shaw and Forbes, 1990a). Photograph by J. Shaw, 18 September 1987. GSC 1998-055B

Figure 27.

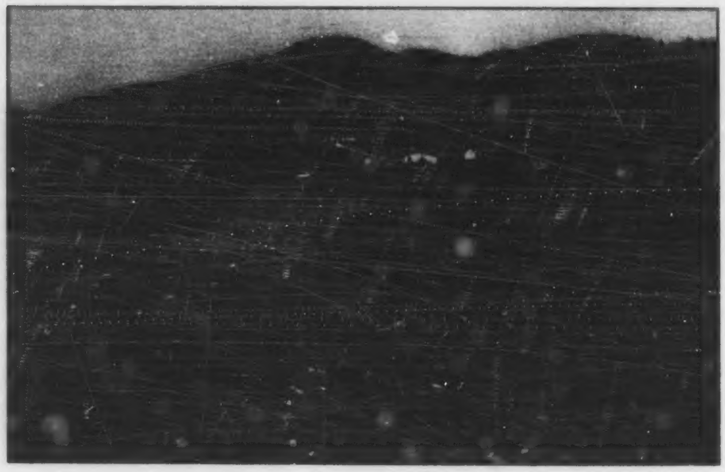
Type 2 coast at the entrance to La Scie Harbour, Baie Verte Peninsula. Note the bedrock ramp and sandy pocket beach. Photograph by J. Shaw, 5 August 1991. GSC 1998-055C

Figure 28.

Type 2 coast on the west coast of White Bay. The rocky headland is about 150 m high. Photograph by J Shaw, 10 August 1991. GSC 1998-055D

Figure 29.

Type 3 coast at Upwards Cove, Green Bay. The steep pebble-cobble-boulder beach is bounded by rock headlands and extends to almost 6 m above mean water level. Photograph by J. Shaw, 22 June 1992. GSC 1998-055E



of Bonavista Bay south of Cape Freels, the southern shore of Fogo Island, many of the islands in Bay of Exploits, large parts of the outer-fiord and island shoreline in Notre Dame Bay, and parts of White Bay. Some type 3 coasts include rock cliffs fronted by wide rock platforms, as in Wild Bight (Beachside), between Halls Bay and Green Bay in region 15. Others, such as the fiord-like coast of Long Island Tickle and the southern shore of Long Island, consist of precipitous rock cliffs.

Type 4: Semiexposed to protected, rock-dominated, fiord coast with limited development of mixed sand and gravel beaches

Type 4 coasts (Fig. 31, 32) are not found in regions 12 and 13, but do occur south of region 12 in Bonavista Bay (Indian Arm being the only example within the study area) and west of the Twillingate area from Bay of Exploits to White Bay and locally to the north along the east coast of Great Northern Peninsula (e.g. Cat Arm and Great Harbour Deep). In some cases, they consist of steep rock slopes that extend below the present sea level. Rock cliffs, often with numerous short pocket beaches at their bases, occupy much of the fiord coast. Cliffs cut into Quaternary sediments occur locally. Extensive, low-energy, mixed sand and gravel beaches have developed in some places, such as Western Arm, Little Arm, and Little Bay Arm north of Halls Bay (region 15).

Type 5: Partly exposed to protected, rock-dominated, low-relief coast with extensive rock and boulder platforms, boulder flats, and locally extensive mixed sand and gravel beaches

Type 5 coasts (Fig. 33, 34) are very extensive from southern Hamilton Sound and Gander Bay to the head of Bay of Exploits near Botwood. They occupy some embayments

Figure 30.

Type 3 coast at Little Bay (immediately west of the entrance to Halls Bay). Small pebble-cobble beaches are found between bedrock cliffs. Photograph by J. Shaw, 14 August 1990. GSC 1998-055F

Figure 31.

Type 4 coast, Halls Bay. Cliffs are found in places; elsewhere, steep, wooded slopes extend down to the water's edge. Photograph by J. Shaw, 12 September 1987. GSC 1998-055G

Figure 32.

Type 4 coast, Wolf Cove, at the head of Halls Bay. The low, pebbly beach is composed of reworked glacial sediments. Photograph by J. Shaw, 12 September 1987. GSC 1998-055H

Figure 33.

Type 5 coast, Hunts Cove, Dog Bay. The coastline consists of alternating sections of bedrock and narrow sand and gravel beaches. Photograph by J. Shaw, 14 June 1992. GSC 1998-055I

Figure 34.

Type 5 coast, Sops Arm, White Bay, showing a typical delta in the study region. Much of the surface consists of cobble gravel. Photograph by J. Shaw, 8 August 1991. GSC 1998-055J farther west in New Bay, Badger Bay, Halls Bay, Green Bay, Baie Verte, and Sops Arm (White Bay); they are found locally elsewhere, but are absent from most of region 12 and from regions 13a, 16 (excluding Baie Verte), and 18. They are typified by a low-relief backshore, extensive, irregular rock outcrop, and widespread boulder platform and boulder flat development locally with ice-formed boulder barricades. Marshes are rare, but beaches are typically low-energy, gently sloping, poorly sorted accumulations of sand and gravel, although some sites exposed to greater fetch lengths (as on the west side of Gander Bay near Victoria Cove) have higher energy beaches with finer sorting. Beaches longer than 2 km are relatively common on type 5 coasts (type 1 being the only other coast type with this feature). Typical locations for beaches of this kind are in fiord heads, for example at the head of Halls Bay where terrace-margin cliffs extend 5 km or more along the side of the bay south of Springdale (Grant, 1989b) and have equally extensive, low-energy, fringing beaches.

Type 6: Protected, rock-dominated, low-relief, shallow embayments with extensive boulder flats

The low-energy, type 6 coasts (Fig. 35, 36) could be considered a subset of type 5; however, they were differentiated because of their distinctive geomorphology and low potential for beach development. These low-relief, boulder-flat coasts are found on the northwest side of Bonavista Bay (in Valleyfield Harbour), along the southern and western shores of Hamilton Sound, Gander Bay, and Dog Bay, in Shoal Bay (Fogo Island), and very locally to the west in Winter Tickle (Bay of Exploits), South Arm (New Bay), Saltwater Pond (Halls Bay), and Northwest Arm (Green Bay)

Distribution of coastal features by region

Figure 37 summarizes the percentage occurrence of various coastal features by region (*see* Fig. 24 for region boundaries). It should be noted that the total percentage for each region is greater than 100 because it represents 17 feature types, many of which overlap along the coast. The most

Figure 35.

Type 6 coast consisting of boulder flats near Musgrave Harbour, on The Straight Shore. Photograph by J. Shaw, 2 August 1990. GSC 1998-055K

Figure 36.

Type 6 coast consisting of a very low-energy environment at the head of Dog Bay, close to the mouth of Dog Bay River. Boulders are strewn across sandy, muddy flats. Photograph by J. Shaw, 17 June 1992. GSC 1998-055L prominent feature on Figure 37 is the steep ramp on the left side of the diagram, which reflects the high percentage of rock outcrop (RO) in all regions, ranging from a minimum of 47 per cent in region 13b to over 95 per cent in regions 13a and 18. Other features with broad representation across the study area (as indicated by ridges extending across the field of Figure 37) are rock platforms (RP) and gravel beaches (GB); their highest percentage occurrence is 25 per cent (for both rock platforms and gravel beaches in region 13b), which again highlights the predominance of bedrock. It is interesting to note that the highest ocurrence of rock platforms is associated with the lowest overall extent of outcrop and is in an area of relatively low wave energy.

Three regions (13, 14, and 15) were subdivided into subregions on the basis of exposure. The shading in Figure 37 distinguishes exposed, outer-coast regions/subregions (light shade: 12, 13a, 14a, 15a, 16, and 18) from more protected, inner-coast settings (dark shade: 13b, 14b, 15b, and 17). Ignoring for the moment the anomalous character of region 12, it is immediately obvious that the two populations (outer coast and inner coast) are differentiated in several ways. Firstly, despite the high proportion of rock outcrop throughout the area, the protected, inner-coast regions/subregions have consistently lower rock outcrop (RO) percentages than adjacent exposed sections. Secondly, beach deposits (GB) are significantly more abundant in the protected subregions (13b, 14b, 15b) and, to a lesser extent, in region 17 than along the outer coast, where rock cliffs (RC) are more extensive (regions 15a, 16, 18, and less so in 14a). Thirdly, the most widespread occurrence of type 5 coasts is in subregions 13b and 14b, as is shown in part by peaks in the frequency of boulder-platform (BP) and boulder-flat (BF)

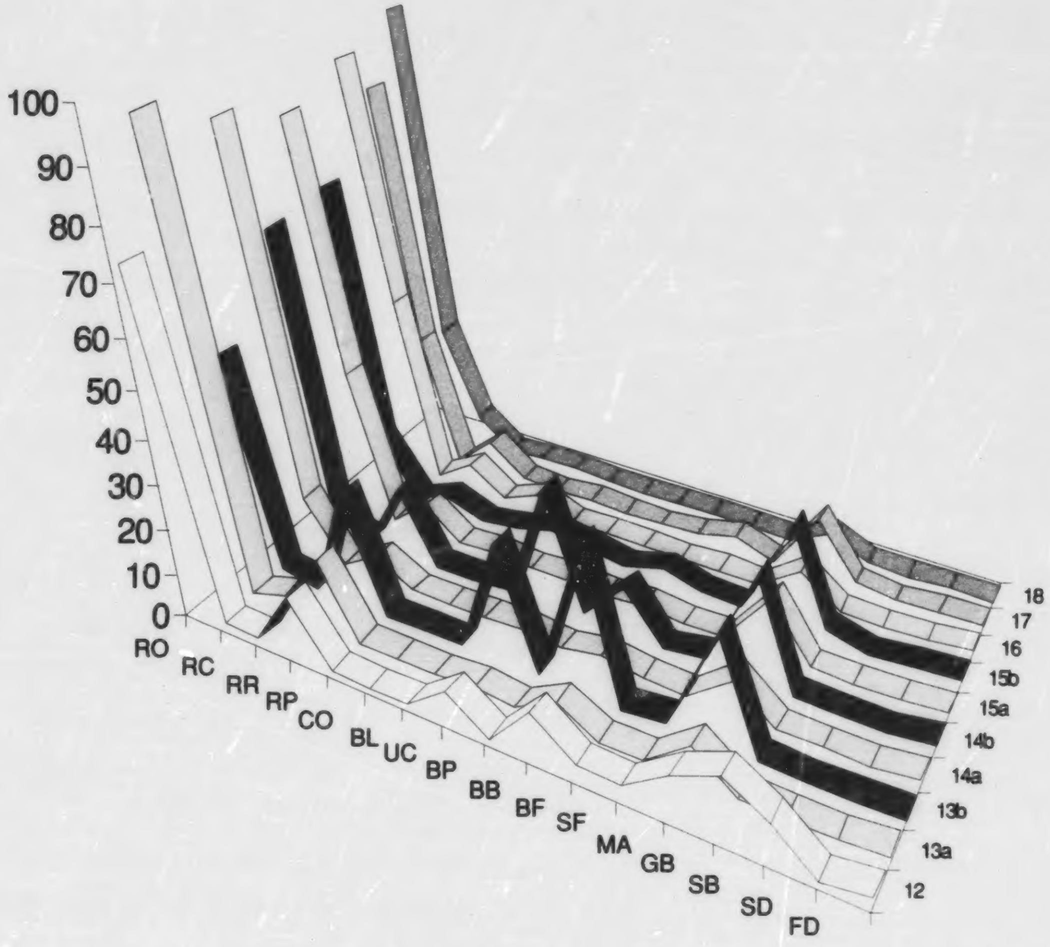


Figure 37. Percentage occurrence of coastal features by region. The regions are shown in Figure 24 and shore-feature notations are given in Table 2.

coasts in these regions. Less obviously, boulder barricades (BB) are most common in subregions 14b (8.5 km or 2.2 per cent) and 15b (4.8 km).

Other distinctive features of Figure 37 include the relatively numerous occurrences of wave-washed rock ramp (RR) in region 18 (9.5 km or 6.4 per cent) and, although less easy to see, in regions 13a (9.3 km) and 15 (3.6 km). Tidal flats without boulders (SF) are most prominent in White Bay (region 17), where they cover 8.3 km (3.1 per cent); they also cover 7.0 km (1.2 per cent) in subregion 15b and 6.1 km (2.7 per cent) in region 12. Although region 12 is the only area with a noticeable percentage of salt marsh (5.5 km or 2.4 per cent), the largest extent of marsh occurs in subregions 14b (6.9 km) and 15b (4.9 km). Overall, however, the distribution of salt marshes in the study area is very limited.

Region 12 differs from the other regions in a number of ways, reflecting the high proportion of type 1 and type 6 coasts in that area. As Figure 37 shows, region 12 is the only area with significant coastal dune development (17.8 km). The dunes are associated with extensive, sandy beaches that occupy 31.1 km (almost 14 per cent) of the region, whereas 21.3 km of shoreline has gravel beach. The only other regions in the study area with more than 1 per cent sand beach are regions 17 (3.7 km) and 15b (14.2 km). Despite the abundance of sand in region 12, rock outcrop still dominates at 73 per cent of coast length and rock platform is present on 13 per cent (30 km) of the coast. The low peaks for boulder platform (7 per cent) and boulder flat (10 per cent) for region 12 reflect in part the presence of type 6 coasts in Ragged Harbour (Hamilton Sound) and south of Cape Freels (Bonavista Bay).

SURFICIAL SEDIMENTS AND GOLD OCCURRENCE

White Bay

White Bay (Fig. 38), the longest bay in the study area, extends 82 km northeastward from its head in Hampden Bay and has a deep, central basin that reaches a maximum

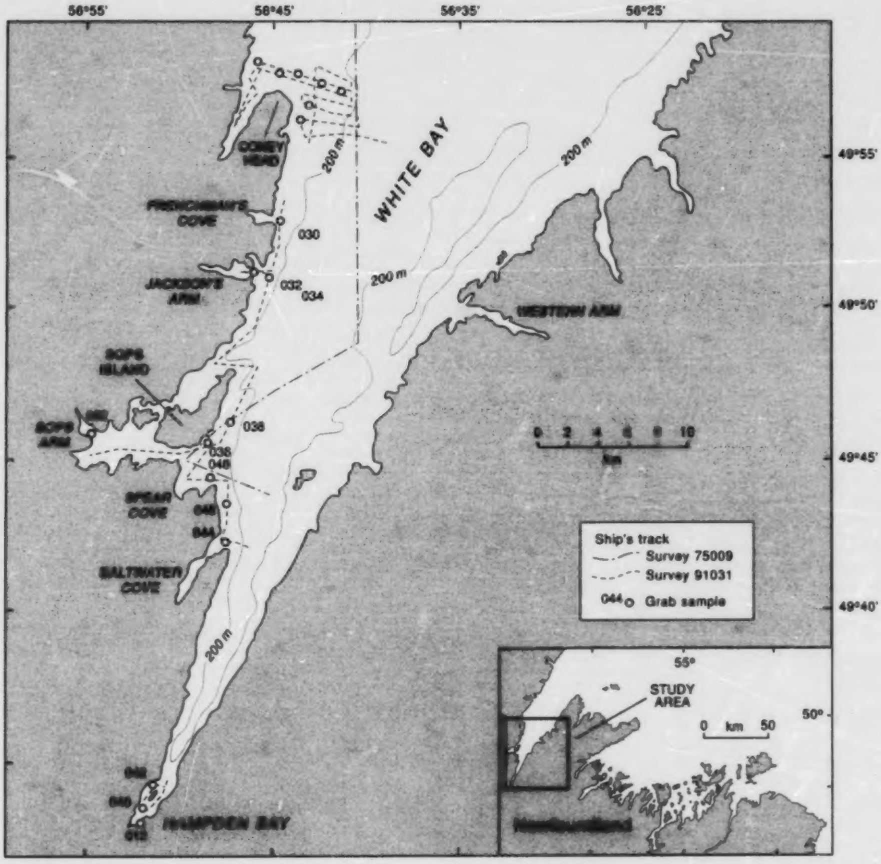


Figure 38. Map of White Bay showing locations mentioned in the text, ship's tracks for two cruises, and sample sites.

depth of 536 m east of Jackson's Arm and shallows northward progressively to 400 m east of Little Harbour Deep. Summaries of Huntec high-resolution seismic reflection data previously collected in White Bay are found in Haworth et al. (1976b), Dale and Haworth (1979), and Shaw and Wile (1990)

White Bay contains varied thicknesses of sediment in its deep, central area and only thin deposits on the landward margins. At the mouth of the bay, southeast of Great Harbour Deep, 30 m of unit 4 (postglacial mud) overlie 5 m of unit 3 (glaciomarine mud) and about 25 m of unit 2 (glacial diamicton). Unit 2 contains several internal reflections, suggestive of at least three subunits. The postglacial mud thins to the southwest where, off Great Cat Arm, it is only 15 m thick, although the glaciomarine unit is still 5 m thick; the thickness of glacial diamicton here is unknown. Southwest of Great Cat Arm, sediment thicknesses increase to a maximum of 60 m for postglacial mud and at least 60 m for glaciomarine mud off Jackson's Arm. Due east of Sops Arm, the bedrock valley is narrow and contains only 40 m of postglacial mud and at least 170 m of the glaciomarine unit. The glaciomarine and postglacial mud units thin considerably on the flanks of the basin. Truncated, internal reflections at the surface of the postglacial unit indicate that the sediments have been eroded by as much as 8 m.

Although the deep, central part of White Bay is obviously unsuitable for development of marine placers, the relatively shallow, wave-dominated zone along the coast was considered to have some potential. The following regions are found along the flanks of the bay in less than 100 m of water, in moderate- to high-energy environments more favourable for the concentration of placer gold. Data interpretation and gold analyses are discussed separately for each region.

Coney Head area

Coney Head is situated on the western margin of White Bay, north of Sops Arm (Fig. 39). Data were collected landward of the 100 m isobath in a region surrounding Coney Head. Great Coney Arm deepens progressively to over 100 m at its mouth west of Coney Head. The seabed surrounding Coney Head, particularly east of the peninsula, comprises a veneer of postglacial, muddy gravel less than 5 m thick, small patches of postglacial sand or mud, and bedrock outcrops. Westward, towards Great Coney Arm, the percentage of bedrock outcropping at the seabed decreases and muddy gravel, sand, or mud predominates. Gravel ripples and

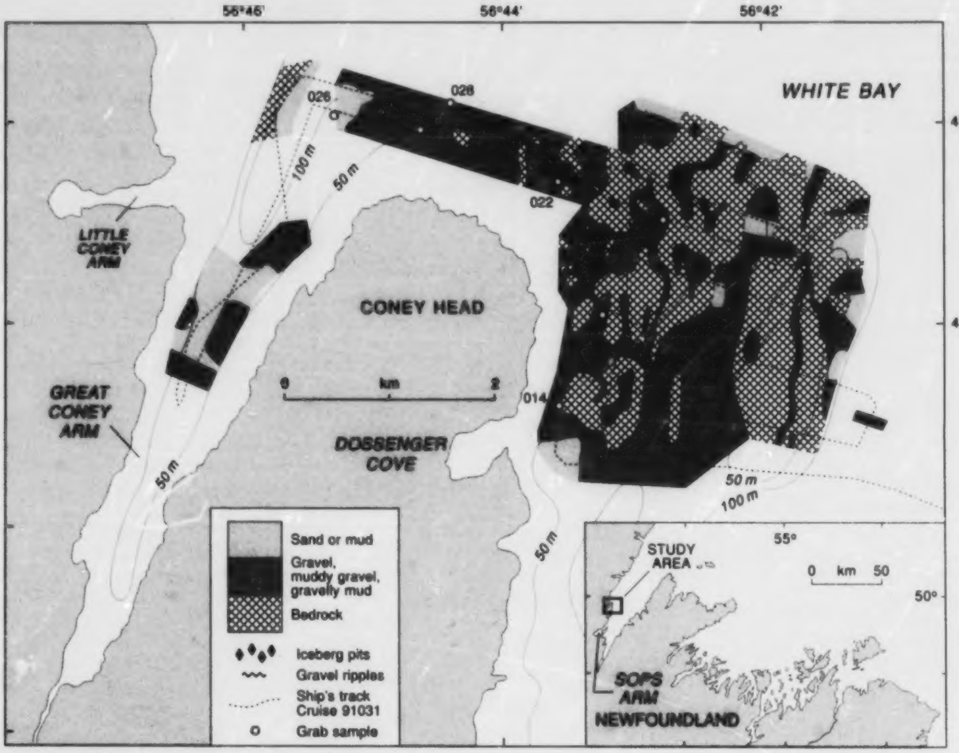


Figure 39. *Map of the Coney Head area of White Bay showing surficial geology and seabed sample sites.*

iceberg pits are present within the muddy gravel. Great Coney Arm contains postglacial, sandy mud less than 10 m thick that overlies up to 42 m of glaciomarine sediment.

Eight van Veen grab samples (91031-014 to 91031-028, even numbers) and eight accompanying colour photographs of the seabed were collected in water depths ranging from 33 to 123 m. All but one of the seabed samples consisted of sand and gravel. The gravel forms a surficial armour several clasts thick, encrusted with *Lithothamnion* sp. Sample 91031-026, from the mouth of Great Coney Arm, consisted of homogeneous, muddy sand. Six of the samples collected in the Coney Head region were analyzed for gold content. Only one (sample 91031-014), collected east of Dossenger Cove in 31 m of water, contained an anomalous gold concentration: 85 ppb in the mud fraction. Particulate gold was not recovered from any of the samples taken from this region.

Jackson's Arm, Sops Arm, Saltwater Cove, and Hampden Bay

Data were collected along a single track line from Jackson's Arm through to Sops Arm, Saltwater Cove, and Hampden Bay (Fig. 38). Except for embayments and coves, the coastline along the western margin of White Bay is defined by steep to inclined bedrock cliffs fronted by a pebble-cobble-boulder beach fringe with isolated sand and gravel pocket beaches. This morphology is cut by several east-west trending inlets along the western side of White Bay.

A narrow, shallow embayment towards the head of Jackson's Arm has a maximum water depth of 26 m. The arm broadens and deepens seaward, forming a circular embayment up to 62 m deep. At the entrance to White Bay, the arm narrows and is confined by the bedrock promontories of Eastern and Western heads.

The second embayment, Sops Arm, is on the west side of White Bay, near its head. The entrance to the embayment is confined by Sops Island and the smaller George's Island, which define the northern limits of South Channel, the main passageway into Sops Arm. The arm reaches a maximum depth of 146 m and shallows to 75 m at the mouth of South Channel near the entrance to White Bay. At the head of Sops Arm and the confluence of Main and Doucers brooks is a small, braided-river delta with subaerial sand and pebble-cobble flats and a delta platform less than 2 m deep and 650 m wide. Beyond the 2 m bathymetric contour, the delta platform steepens abruptly towards the centre of the basin. Elsewhere, the 20 m bathymetric contour lies within 200 m of the shoreline.

Spear Cove is a wide, relatively exposed embayment up to 53 m deep, which forms part of the southern boundary of South Channel and defines the outer southeastern margin of Sops Arm. Farther south, Saltwater Cove forms a larger, more protected embayment along the western margin of White Bay with water depths up to 16 m. At the head of the cove, a well developed gravel barrier with a narrow tidal channel connects the cove to Saltwater Pond.

Lastly, Hampden Bay lies at the head of White Bay, forming an oblong embayment that surrounds Millers Island and reaches a maximum water depth of 133 m. Hampden River enters the bay via a fiord-head sand and pebble-cobble delta with extensive subaerial distributary-mouth flats.

Along the marginal benches of the White Bay fiord and within the coves along the western side of the bay from Jackson's Arm to Hampden, the seabed consists of numerous bare bedrock outcrops protruding from a thin, discontinuous veneer of postglacial sand, gravel, and mud overlying bedrock. Pockets of Quaternary sediment reach thicknesses of 14 m in Jackson's Arm, up to 49 m in Sops Arm, 39 m in Spear Cove, 4 m in Saltwater Cove, and 18 m in Hampden Bay. Smaller pockets of sediment exist along the more wave-exposed margins of the bay.

Ten van Veen grab samples were collected from north of Jackson's Arm to Hampden Bay in the south (Fig. 38). Samples collected along the exposed western shore of White Bay (Frenchman's Cove [sample 30], Jackson's Arm [samples 32 and 34], near the mouth of Sops Arm [samples 36 and 38], Saltwater Cove [sample 44], Lower Head [sample 46], and Spear Point [sample 48]) consist of moderately to poorly sorted, muddy sand and gravel. At the head of White Bay, within the comparatively protected environment of Hampden Bay (samples 40 and 42), the bottom consists of sandy mud with a surface lag of gravel. Seven of the ten samples were analyzed for gold in the mud and sand fraction. In addition, gold analyses were completed on one hand-trowel sample (sample 13) from Hampden Beach and another (sample 52) from the mouth of Main River at the head of Sops Arm. Gold values in all samples were less than 21 ppb.

Baie Verte

Baie Verte, a 20 km long embayment on the north side of Baie Verte Peninsula (Fig. 40), is the most intensively surveyed part of the study region, mainly due to the early discovery of anomalous levels of gold in grab samples (Shaw et al., 1990, 1991), particularly from Deer Cove. Preliminary assessments of the data were presented by Jenner and Shaw (1992), in cruise reports (Shaw and Wile, 1990; Shaw et al., 1990), and in a comprehensive account of the surficial sediments of the bay (Shaw, 1992). Edwardson et al. (1992) reported on a survey of nearby Ming's Bight, which had not been mapped previously mainly because it was poorly charted.

Southwest of the bedrock sill at the mouth of the bay (water depth 192 m), a bedrock trough has a maximum depth of 324 m just northwest of Deer Cove. In the outer bay (i.e. seaward of Duck Island), the seabed on either side of this trough is highly irregular, with shoals and rocky islands. Shallow bedrock shelves are found in coastal embayments, particularly at Devil's Cove (average depth 28 m), Deer Cove (46 m), Coachman's Harbour (28 m), and Marble Cove (28 m). In contrast, inner Baie Verte is shallow and gently shelving; its maximum depth is 71 m just west of Pine Cove. The delta of the Baie Verte River shelves gently into the bay.

In the outer bay, bedrock exposures are common and typically project through a veneer of muddy gravel or gravelly mud; however, in the inner bay, bedrock exposures are less common. Glacial diamicton (unit 2) does not occur in the outer bay, but in the inner bay, several deposits overlie bedrock, commonly covered by a veneer of postglacial sediments, either muddy gravel or gravelly mud. Where these sediments are thin, boulders on the seabed indicate the presence of glacial diamicton just below the surface. Glacial diamicton deposits extend from Duck Island to Green Cove (maximum thickness 24 m), between Shark Point and Pumbly Point (17 m), and in a zone that extends across the bay from Pine Cove and along the west coast to the head of the bay (11 m).

Stratified, glaciomarine sediments (unit 3) in the deep, outer bay reach a thickness of 70 m. In the inner bay, unit 3 forms a thin (5–10 m), conformable drape over either bedrock or glacial diamicton. Gravity cores (90035-133, 90035-134, and 90035-135) that intersected this unit show that it is composed of grey, gravelly, sandy clay. An undetermined thickness of postglacial mud (unit 4) occurs in the deep trough of the outer bay. In the inner bay, ponded

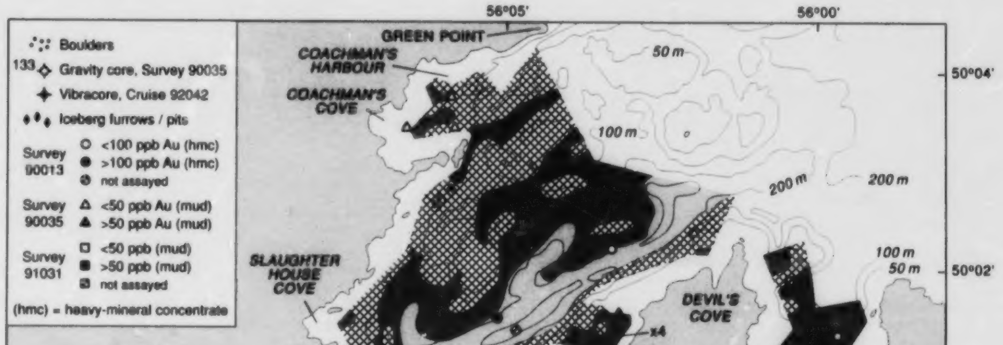


Figure 40. Map of Baie Verte and Ming's Bight showing surficial geology and seabed sample sites.

deposits of mud or sandy mud occur in the deeper areas and grade into sandy mud or muddy sand close to the coast. Except in the inner bay and the central trough of the outer bay, much of the seabed has a thin veneer of gravelly, postglacial mud overlying bedrock.

Wave energy increases from the inner bay to the outer bay and, as might be expected, the sediments on the shallow embayment shelves of the outer coast are sand and gravel (unit 5). Well sorted, medium sand occurs in Coachman's Harbour and fine sand, in Marble Cove. Deer Cove contains sediments up to 17 m thick (*see* Fig. 17). A thin (0.5 m), surficial layer of sand and gravel overlies finer grained sediments that may have been deposited under lower energy conditions and a higher wave base than those of today (the relative sea level was about 15 m higher at 8.5 ka). Gravel ripples are present and the seabed also shows evidence of pitting by iceberg impact.

Of 12 samples collected in Baie Verte during CSS *Hudson* cruise 90013, five had over 90 ppb Au in the heavy-mineral concentrate. The highest concentration (1650 ppb) was from Green Cove (Shaw et al., 1991). During cruise 90035, 36 samples were collected in Baie Verte, of which 35 were analyzed. Of these, 11 contained anomalous (>50 ppb) gold in the mud fraction (Emory-Moore, 1991). The top five values, ranging from 224 to 859 ppb, were from Deer Cove, where the gold is contained in the upper sand and gravel unit. Emory-Moore (1991) noted two populations of gold grains at Deer Cove, a population with fresh, irregular features and low Ag content that had travelled a very short distance (<500 m) from the site of liberation, and a population with regular morphologies, percussion marks, chemical pitting, and high Ag levels that has had a longer history of transport and may be far from its source. The source of population 1 could be the Deer Cove gold deposit, situated 1 km from the coast. Alternatively, the gold could have been liberated from a submarine bedrock source. The source of population 2 is unknown.

Possible mechanisms that could account for the presence of gold in the sand at Deer Cove are 1) deposition by a local stream, 2) winnowing by waves of pockets of gold-rich, glacial diamicton, and 3) winnowing by waves and iceberg impact of gold-bearing, early Holocene marine sediments. Deer Cove was at one time the favoured location for an experimental marine mining study by C-CORE. However, it is also fished extensively and after discussions with local interests, the C-CORE study site was moved to Pine Cove (ultimately, the project was not funded). The limited volume of the postglacial sand unit at Deer Cove and the low wave energy and lack of a winnowing mechanism at Pine Cove make either place an unlikely prospect for economic levels of gold. However, it has been suggested that Deer Cove could be the site of a cottage-style mining operation (M. Emory-Moore, pers. comm, 1992).

Ming's Bight

Ming's Bight is a small embayment east of Baie Verte (Fig. 40). Most of the bay is shallower than 100 m and the seabed is highly irregular. Quaternary sediments are typically less than 2 m thick in the central part of the bay and have an average thickness of 5 m in several of the deeper basins. On sidescan sonar records, the seabed has a predominantly dark tone with lighter mottles and several extensive, light-toned patches of smooth (muddy) bottom. The sediments consist of a veneer of mud or gravelly mud overlying bedrock. Much of the seabed shows evidence of iceberg pitting. The sediment veneer may be a mixture of glaciomarine mud, postglacial mud, and ice-rafted gravel. The sediments become coarser towards the mouth of the bay. Of nine samples analyzed for gold from Ming's Bight (Emory-Moore and Davis, 1992), only one, from the intertidal zone at the head of the bay, contained significant gold (102 ppb) in the mud fraction. Given the thinness of the sediments, the moderate to low wave energy in the bay, and the lack of reworking of the seabed (other than turbation by iceberg impact), the area's potential to host economic levels of marine placer gold is low.

Inner shelf north of Baie Verte Peninsula

The north coast of Baie Verte Peninsula has steep bedrock slopes and cliffs up to 150 m high. The area between the mainland and the Horse Islands (Fig. 41) is a basin with an average depth of 220 m. It is bounded to the west by a bedrock ridge that extends southwest from the Horse Islands and lies at a depth of 120 m in the shallowest areas. On the southeast side of the basin, between Confusion Bay and Cape St. John, the seabed is rugged and pinnacles reach to within 35 m of the sea surface.

Quaternary sediments are thin in this region (*see* Jenner and Shaw, 1992). In the basin, bedrock is overlain by a thin (up to 5 m) drape of glaciomarine mud (Fig. 42, profile A) above which is a patchy cover of postglacial mud up to 4 m thick at the south side of the basin. Internal reflections are locally truncated at the seabed, suggesting that erosion has taken place. The postglacial mud thins towards the basin margins, so that the underlying glaciomarine mud is exposed on the seabed. Iceberg furrows disrupt the Quaternary sediments above a depth of 190 m in the eastern

Figure 42.

Interpretation of Huntec records from the inner shelf between the Horse Islands and Baie Verte Peninsula. Profile A shows units 3 and 4 overlying bedrock. On profile B (shallower water), the uppermost unit is largely absent and the glaciomarine unit (3) has been turbated by icebergs.

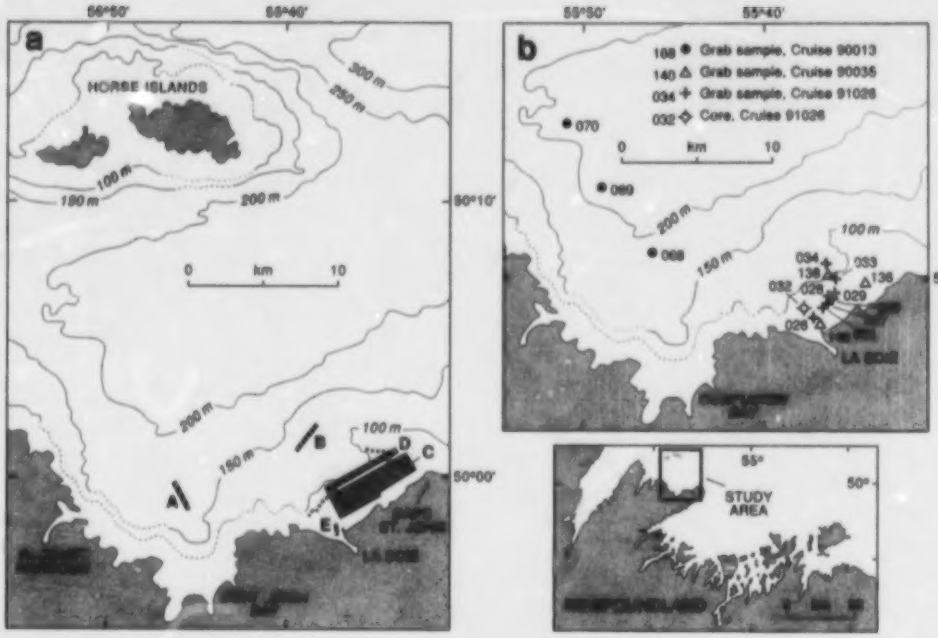
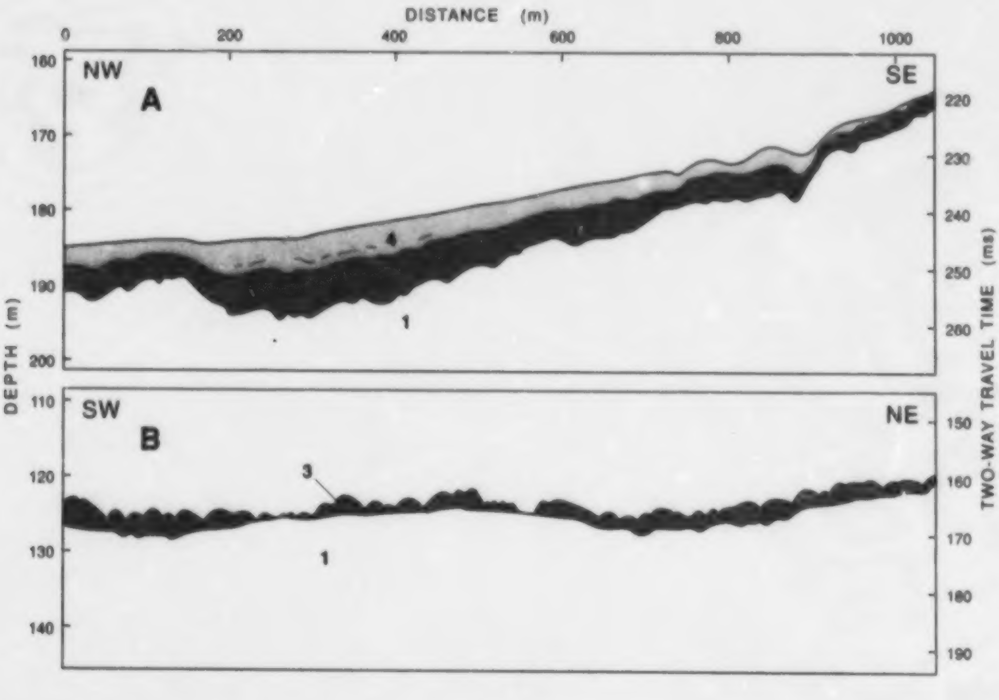


Figure 41. *Bathymetry of the area between Baie Verte Peninsula and the Horse Islands. A and B are the locations of interpreted seismic profiles shown in Figure 42, C is the sidescan-sonar mosaic shown in Figure 43, D is a sidescan sonar record showing iceberg pitting (Fig. 44), and E is a sidescan-sonar record showing gravel ripples (Fig. 45). The dashed line running through the mosaic area is the 90 m contour, which is the approximate boundary between two zones mapped by Shaw (1991).*



part of the area (Fig. 42, profile B). With decreasing water depth, the internal stratification is increasingly disrupted and in shallow areas, it is absent, giving the sediment the appearance of an iceberg turbate. Wave action likely has a significant impact on the seabed in water shallower than 90 m and is the dominant force at a depth of less than about 70 m, resulting in a coastal fringe of mobile sand and gravel that is several kilometres wide.

A small area offshore from La Scie was subject to more intensive scrutiny than elsewhere in the region, partly because it was within reasonable travelling distance from the harbour, but primarily because it spanned several shore-parallel zones. The area mapped by Shaw (1991) shallows from 140 m in the northwest to 70 m about 1 km offshore in the southeast and to 50 m at the entrance to La Scie Harbour. Two depth-dependent zones, the inner zone and the outer zone, have been identified below and above a depth of 90 m on the basis of the character and mobility of seabed sediments. The sidescan sonar mosaic in Figure 43 overlaps both zones and the dashed line on Figure 41 shows the zone boundary.

Outer zone

In this relatively deep zone, the Quaternary sediment cover is generally continuous with an average thickness of several metres and a maximum thickness of 10 m; bedrock is

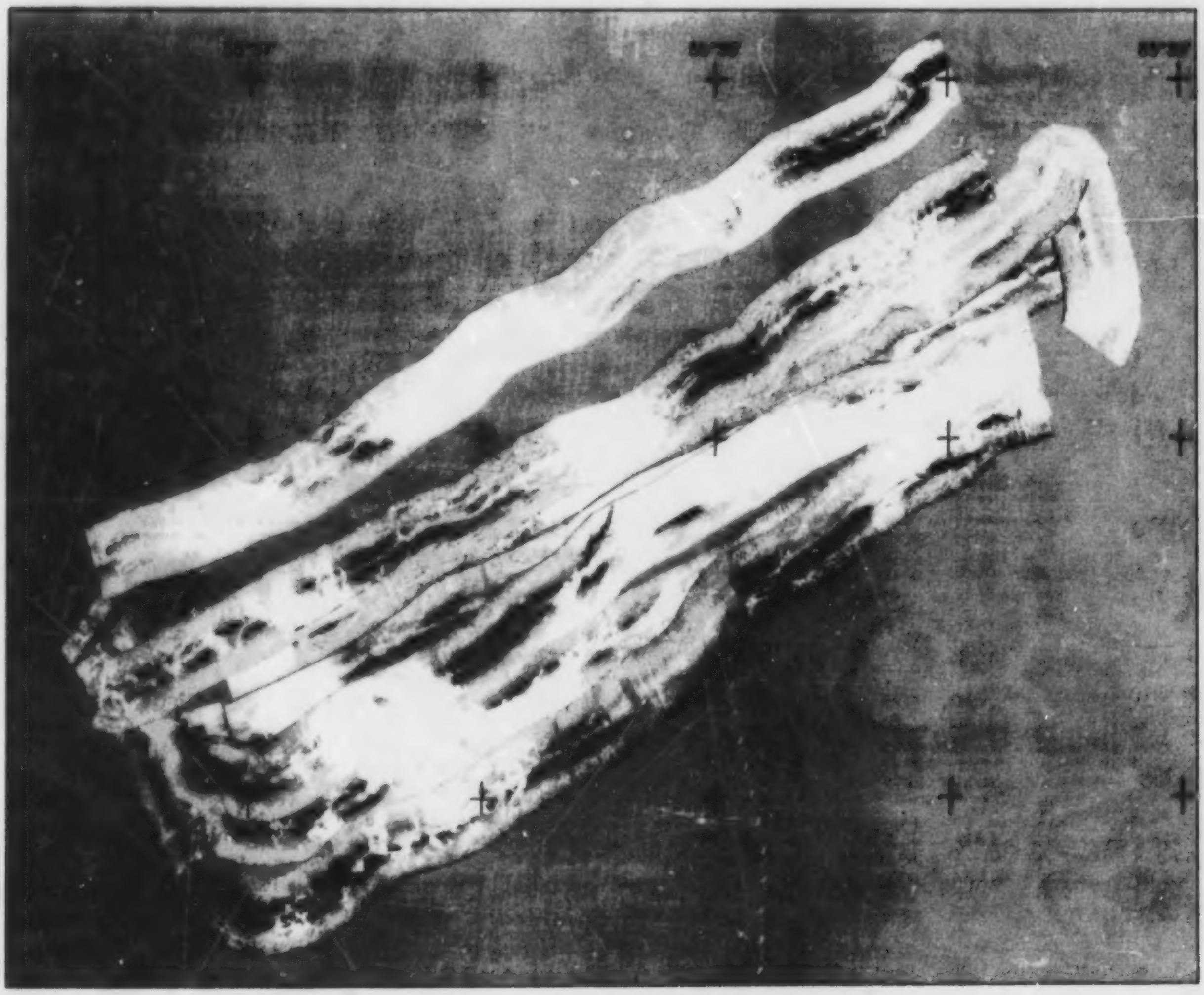


Figure 43. *Digital sidescan sonar mosaic from an area north of La Scie showing the patchy distribution of fine sediment on the seabed (light tones). Iceberg impact marks are not visible at this resolution, but are seen on the sidescan record (Fig. 44). The extensive areas of gravel ripples that are found in this region are also not visible, but are shown on Figure 45.*

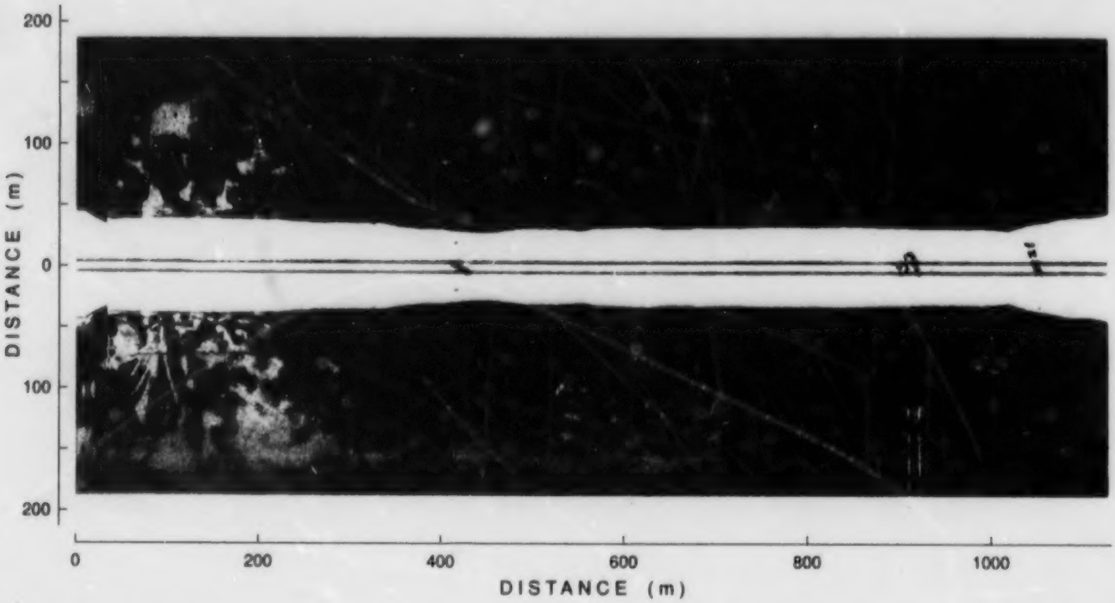


Figure 44. *Klein 421 sidescan sonar record from an area north of La Scie (location shown in Figure 41), showing the results of intense iceberg impact. Pitting is predominant although furrows are also present in places.*

exposed on ridges. The sediment shows incoherent reflections and its upper surface is highly irregular, with relief up to 3 m, due to the presence of linear features up to 5 m wide that are interpreted as iceberg furrows. On sidescan sonar records, the seabed is dark (highly reflective) except for the inner part of furrows, which are light toned. The sediment is acoustically unstratified, but below about 190 m depth (outside the limits of the study area), it passes laterally into sediment containing low- to moderate-intensity, continuous, coherent reflections, conformable with the surface of the underlying bedrock. Furrows are not evident in water depths below about 190 m. At the landward margins of the zone, iceberg pits are more prevalent (Fig. 44); they are typically about 15 m and up to 30 m in diameter, circular to oval in plan, and commonly fringed by berms. The seabed within these berms has a light tone on sidescan sonar records, indicating the presence of fine-grained sediment, probably fine sand. The iceberg furrows and pits are rarely observed in areas with water depths less than 90 m, in part because of more frequent reworking of the seabed by waves in shallower water.

The surficial sediment in this outer zone is interpreted as an iceberg turbate: glaciomarine sediment, once stratified, but subsequently sufficiently impacted and disturbed by icebergs to destroy acoustic stratification. Fine sediment partly fills depressions in the iceberg turbate, especially in shallower water close to the upper limit of the zone. Sample 90035-138 (water depth 110 m) is from such a zone where acoustically unstratified sediment about 1 m thick, composed of very fine sand, overlies the iceberg turbate in a depression (Emory-Moore, 1991).

Three grab samples from the outer zone (90013-068, 90013-069, and 90013-070) consisted of sandy, gravelly mud and contained less than 5 ppb Au (Shaw et al., 1991). A fourth sample (90035-138) had 0 ppb in the mud fraction (Emory-Moore, 1991).

Inner zone

The second zone extends inshore from depths of about 90 m. Bedrock outcrops are common on the seabed. On several survey lines, the bedrock has steep seaward escarpments, typically 12–15 m high, but up to 25 m high in one area. Depressions up to 15 m deep contain acoustically unstratified sediment with an irregular upper surface, probably iceberg turbate, that is overlain by a veneer of sand 1 m thick and up to 3 m thick in the sandy area just north of the site of sample 90035-136. Close to the coast, mobile, rippled gravel is also common on the seafloor and in places is partly overlain by sand. Off the mouth of La Scie harbour, large patches of gravel ripples with an average wavelength of 2.8 m (Fig. 45) occur in water depths of 45 to 55 m. Sample 90035-140 was collected there and consisted of a polymodal, sandy gravel with modes at -5.7, -4.7, +1.0, and +2.0 ϕ (51, 26, 0.5, 0.25 mm). (This sample also contained a beer can!) Just seaward of this area, smaller patches of gravel ripples occur in water depths of 67 to 71 m.

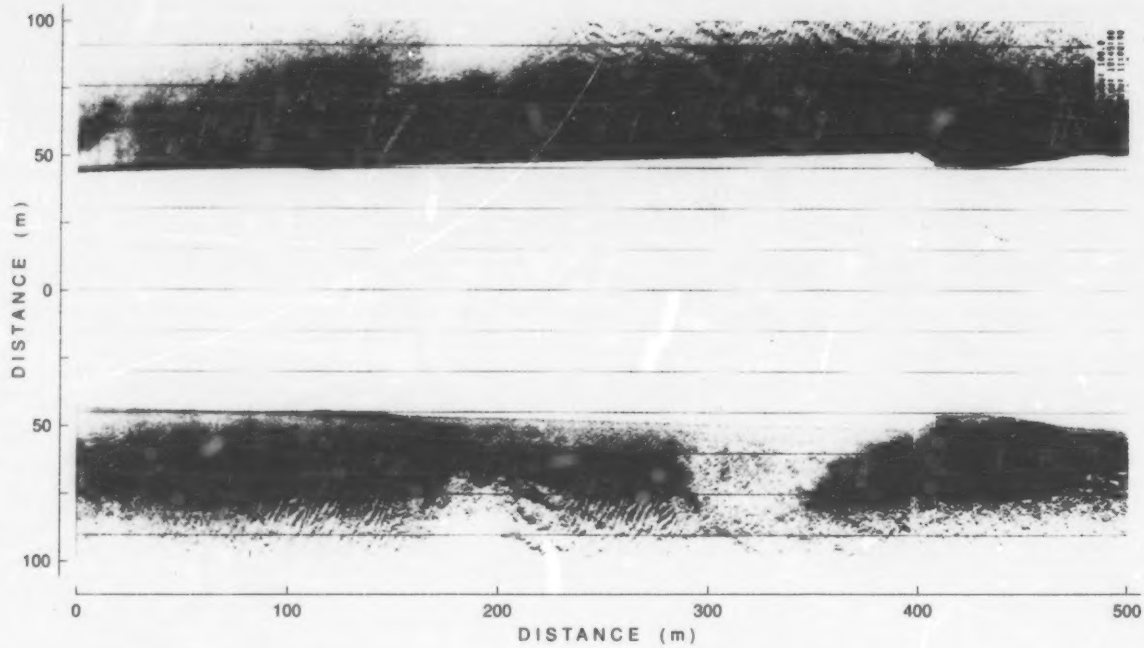


Figure 45. *Klein 595 sidescan sonar record collected in water depths of 50–55 m off the mouth of La Scie Harbour, showing gravel ripples on the seabed. Location shown in Figure 41. A grab sample from within the gravel-ripple field (90035-140) consisted of polymodal, sandy, fine gravel.*

Northeast of La Scie, extensive areas of rippled gravel occur in water depths of 76 to 82 m. Sample 90035-136 was collected in this area and was described as medium sand with some fine gravel. Gravel ripples in the area had an average wavelength of 1.7 m.

The extensive occurrences of rippled gravel attest to the mobility of sediments under waves. The range of water depths in which ripples occur is similar to that on the inner Scotian Shelf, where Forbes and Boyd (1987) reported gravel ripples in water depths from 15 to 65 m. The lack of iceberg furrows and pits on the seabed, in a region where iceberg grounding is common, is due to the mobility of gravel and sand in the inner zone.

Some grab samples from the inner zone contained gold. In sample 90035-136 (water depth 83 m), gold levels were 684 ppb in the mud fraction (1050 ppb in a duplicate) and 3.5 ppb in a panned sample (Emory-Moore, 1991). Two of the IKU grab samples obtained during cruise 91026 contained over 50 ppb Au in the mud fraction (Emory-Moore and Davis, 1992). These were samples 026 (109 ppb) and 027 (249 ppb), which both contained a bimodal population of particulate gold comprising many abraded (well travelled) grains and a lesser number of fresh grains. IKU grab samples 029, 030, 031, 033, and 034 had less than 50 ppb Au in the mud fraction, but also contained particulate gold.

The sources of these small amounts of gold in the inner zone off La Scie were either glaciomarine sediments that have been winnowed by waves and iceberg impact or, as Emory-Moore (1991) suggested in the case of sample 90035-136, offshore mineralized bedrock. Although the host sediments — the sands and gravels of the wave-dominated inner-shelf zone — are thin, they occur over a long, narrow strip that lies just offshore from the exposed, rocky north and northeast coasts of Baie Verte Peninsula. Gold in Deer Cove occurs in such an environment.

Tilt Cove and vicinity

The east coast of Baie Verte Peninsula is fringed by a narrow, rocky, inner shelf. Taking the 182 m (100 fathom) isobath as its outer limit, the shelf widens from less than 1 km at the mouth of Green Bay, to 1.5 km off Betts Cove, about 5 km off Tilt Cove, and 7 km off Bluff Head (Cape St. John). Near Tilt Cove, water depths reach 100 m within 1.1 km of the shore off Scrape Point (Fig. 46). Precipitous, rocky cliffs rising to 100 m or more dominate the shore and are broken only by narrow valleys at Tilt Cove and Beaver Cove. Beaches are virtually nonexistent. Cliff-base debris accumulates below water level, where high-energy waves may effectively move much of it to deeper water. Stream sediments are partly trapped in freshwater basins.

The area of detailed surveys covers a shore-parallel zone that lies between the 50 and 100 m isobaths and is about 2 km wide. It is broadly similar to that surveyed off La Scie in that it encompasses two zones, an inner zone (very narrow in this case) in which wave processes are dominant and only a small portion of which could be surveyed because of the presence of fishing nets close to the coast, and a relatively deep, outer zone that is impacted by icebergs. During the survey of the outer zone on 2 July 1991, an iceberg was observed grounded at a depth of 90 m just southwest of the area shown in Figure 46.

Between the 50 and 100 m isobaths, the irregular seabed consists of a number of broad shoals, closed basins, and seaward-opening depressions extending from south of Scrape Point, from Tilt Cove, and from southeast of Beaver Cove Head. Bedrock outcrops extensively throughout this area and the surficial sediment cover is predominantly thin. Isolated pockets of sediment up to 50 m thick are scattered throughout the survey area and partly fill the basins and valleys. The seabed has an almost ubiquitous mottled pattern interpreted as a product of widespread iceberg impact. A number of sharply defined furrows and pits, produced by

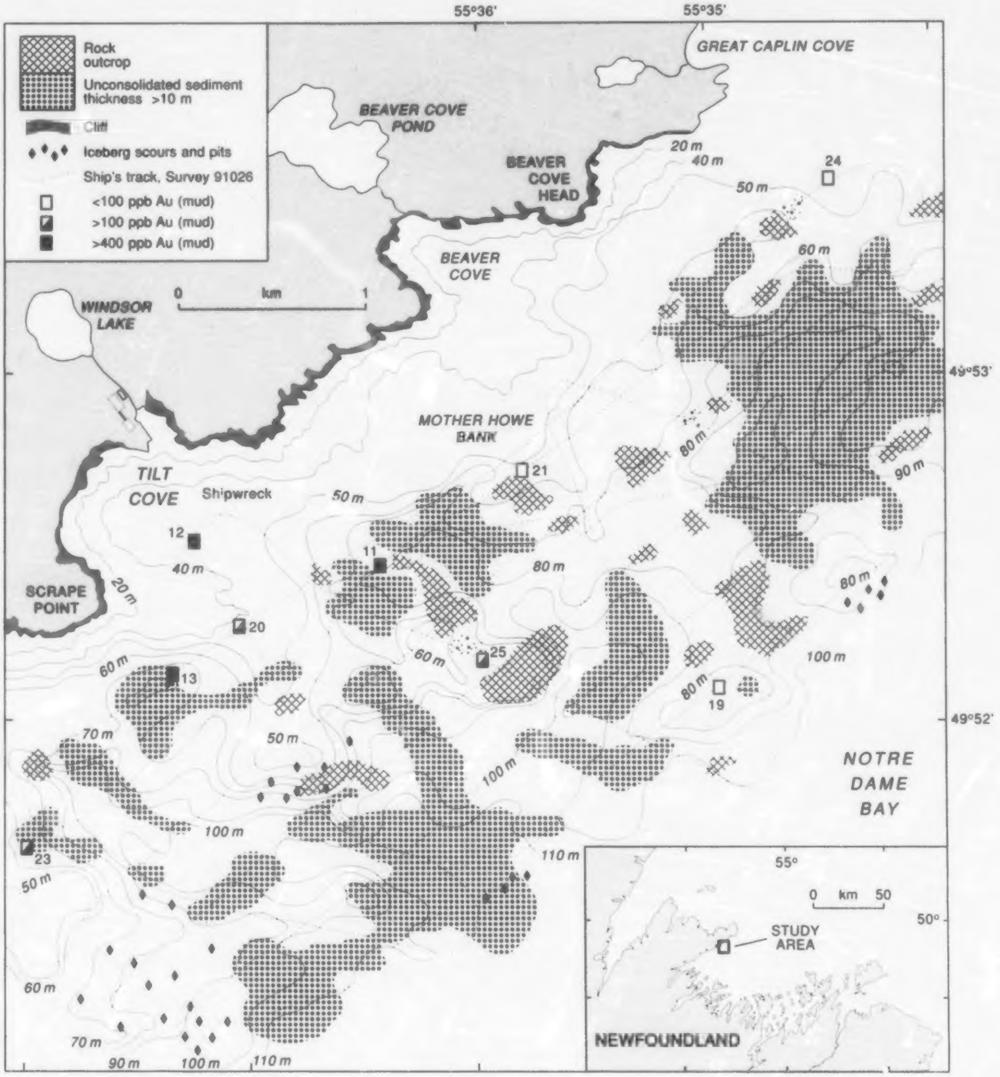


Figure 46. Map of the area off Tilt Cove, on the east coast of Baie Verte Peninsula.

recent iceberg impact, can be identified in the 1991 sidescan records and are plotted individually on Figure 46. Most lie on the seaward flanks of shoals in water depths between 50 m and 110 m.

In 1990, 14 van Veen samples were collected from the area from the CSS *Hudson* in water depths of 102–297 m (Shaw and Wile, 1990). The samples from deeper water consisted of sandy muds and gravelly, sandy muds; samples from shallower water consisted of 0–47 per cent gravel ($D \geq 2$ mm), 9–72 per cent sand ($0.063 \leq D < 2$ mm), and 2–91 per cent mud ($D < 0.063$ mm). Four samples, from water depths between 103 m and 293 m, contained up to 510 ppb Au in the heavy-mineral concentrate, but only up to 14 ppb in the whole samples (Shaw et al., 1991).

Nine IKU grab samples were collected during CSS *Dawson* cruise 91026 (Shaw et al., 1992) in water depths between 47 and 84 m (Fig. 46). Gravelly sand generally occurs in water depths of less than 67 m and probably extends close to the coast. Samples from farther offshore are typically mixtures of sand and gravel, although this reflects a sampling bias, i.e. the muddy basins were avoided. Sediment from sampled basins was fine grained (e.g. sample 012 from the basin off Tilt Cove comprised 80 per cent mud and only 20 per cent sand). Samples 11 to 13, close to Tilt Cove in water depths of 47 to 82 m, were sandy mud or almost equal admixtures of mud and sand with less than 1 per cent gravel, whereas samples 19 to 25 consisted of sandy gravels with less than 5 per cent mud (Emory-Moore and Davis, 1992, Appendix B). Gold concentrations in the mud fraction of samples taken off Tilt Cove ranged from 53 to 536 ppb (eight assays from three samples gave less than 400 ppb), whereas the maximum concentration in the sand fraction was 117 ppb (Emory-Moore and Davis, 1992, Appendix C). Panning produced one sand-sized ($D = 170$ μm) grain in sample 21 and five grains ($70 < D < 150$ μm) in sample 24 (three from a surface subsample and two from the subsurface over 0.5 m below the seabed). All the grains were somewhat abraded and etched and the silver content ranged from 0 to 6 per cent by weight.

The Ordovician Betts Cove ophiolite complex outcrops onshore between Tilt Cove and Nippers Harbour to the southwest. Ultramafic rocks are in fault contact with overlying pillow basalt to the south (Al, 1990). In coastal cliffs, red-brown Ordovician chert, shale, and siltstone and purple and buff Silurian volcanic rocks and sandstone of the Cape St. John Group are exposed above the basaltic breccia (Hibbard, 1983; Colman-Sadd and Scott, 1994). Quartz-magnesite-copper-sulphide gold enrichment occurs in talc-magnesite-altered portions of the ophiolite (Al, 1990). Gold also occurs in quartz veins with varied amounts of magnetite, copper, and iron sulphides in quartz-hematite-dolomite assemblages of the ophiolite and in shear zones within the Cape St. John Group (Al, 1990). The onshore epigenetic deposit at Tilt Cove was mined from 1864 to 1917 and again from 1957 to 1967, producing a total of 43 000 ounces of gold and 153 000 tonnes of copper (Colman-Sadd and Scott, 1994). The Nugget Pond gold deposit (Emory-Moore, 1991) had reserves of 192 000 ounces of gold.

Some contamination of nearby seabed sediments may have occurred from loading operations at the wharf or from shipping losses (at least one wreck is present off Tilt Cove). The highest gold concentrations in samples from the inner shelf off Tilt Cove lie within 1.5 to 6.5 km of known onshore occurrences. Elevated concentrations of iron, copper, and zinc in surficial sediments sampled off Tilt Cove may be associated with the types of mineralization noted above (Emory-Moore and Davis, 1992). The patchy surficial sediment cover in the area could represent a secondary source for autochthonous placer formation by iceberg turbation and wave winnowing processes. Alternatively, the gold may be derived from local sources in bedrock exposures on the seafloor. From the existing data, it is impossible to determine which of these alternatives applies, but the placer potential of the area may be higher if the secondary-source hypothesis proves to be correct.

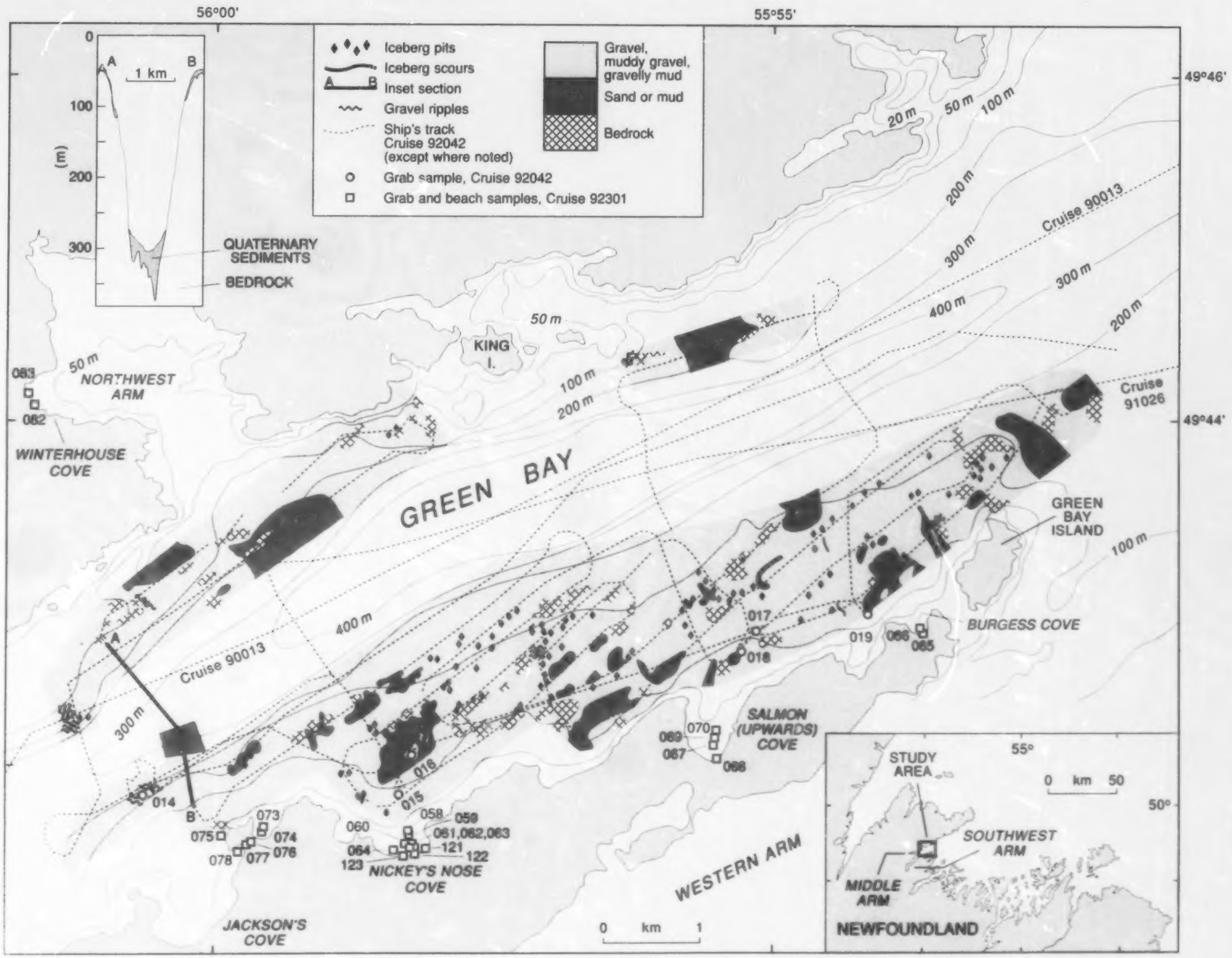
Green Bay

Green Bay (Fig. 47) is a fiord that is divided headward into two branches, Middle Arm and the longer main branch of Southwest Arm. Northwest Arm is a small embayment extending westward from the north side of the outer fiord. The fiord widens from approximately 1 km in lower Southwest Arm to 4 km in the outer reaches near Green Bay Island. Green Bay extends 27 km southwest-northeast from the head of Southwest Arm to Green Bay Island, where it opens into Notre Dame Bay (Fig. 47). The fiord is more than 400 m deep in the outer reach from Northwest Arm to Green Bay Island, to a maximum depth of 450 m. At the entrance to Notre Dame Bay, it shallows to 350 m.

Green Bay contains ponded Quaternary sediments with a thickness of at least 140 m in a narrow trough bounded by steep sidewalls with slopes locally over 50°. The morphology of the fiord and the thickness of surficial sediments along section AB are shown in Figure 47 (inset). A broad bench up to 1.2 km wide, with a slope of 3° or less, is found

Figure 47.

Map showing surficial materials in Green Bay, based on sidescan sonar data only. The central axis of the bay was too deep for sidescan observation, but other acoustic-profiler data show postglacial mud overlying thick, glaciomarine sediments. The inset at top left shows a profile along line AB.


56°00'
55°55'
49°46'
49°44'
Iceberg pits
Iceberg scours
A B Inset section
Gravel ripples
Ship's track Cruise 92042 (except where noted)
Grab sample, Cruise 92042
Grab and beach samples, Cruise 92301
Gravel, muddy gravel, gravelly mud
Sand or mud
Bedrock
0
100
200
300
(m)
A
B
1 km
QUATERNARY SEDIMENTS
BEDROCK
GREEN BAY
KING I.
NORTHWEST ARM
WINTERHOUSE COVE
GREEN BAY ISLAND
BURGESS COVE
SALMON (UPWARDS) COVE
WESTERN ARM
NICKEY'S NOSE COVE
JACKSON'S COVE
Cruise 90013
Cruise 91026
20 m
50 m
100 m
200 m
300 m
400 m
014
015
016
017
018
019
058
059
060
061,062,063
064
065
066
067
068
069
070
073
074
075
076
077
078
082
083
121
122
123
0 km 1
STUDY AREA
SOUTHWEST ARM
MIDDLE ARM
NEWFOUNDLAND
55°
50°
0 km 50

at water depths of between 50 and 100 m along the south side of the bay; a narrow bench is present at water depths of between 100 and 200 m along the north side.

This project focused on outer Green Bay (Fig. 47), where relatively high wave energy increased the potential for shallow marine placers. The bay's southern shore comprises volcanic, volcaniclastic, and associated Cambrian–Ordovician sedimentary rocks of the Lushs Bight Group (Neale and Kennedy, 1967). Intrusive gabbro and diabase occur near Upwards Cove and along the north shore of the bay (Colman-Sadd et al., 1990). Cambrian–Ordovician granitic intrusives are present around the head of Northwest Arm.

Quaternary deposits in the deep fiord consist of stratified, glaciomarine facies (unit 3) overlain by postglacial mud (unit 4); they reach a combined maximum thickness of 165 m in the centre of the bay. The glaciomarine sequence thickens seaward and is up to 120 m thick along a section north of Upwards Cove where it occupies a trough extending to 400 m below the present sea level. Three units are identified along this section. The basal 85 m of sediment produce weakly stratified to acoustically incoherent reflections with a hummocky upper surface (unit 2). The unit is overlain by up to 35 m of glaciomarine sediment characterized by acoustically weak, horizontal reflections (unit 3). The upper unit is up to 45 m thick and is weakly stratified to acoustically unstratified (unit 4).

The sidewalls and marginal benches of the fiord carry a veneer of postglacial mud, sand, and gravel in varied proportions, with numerous bedrock outcrops (Fig. 47). Wave-formed gravel ripples are present in a number of places on both sides of the bay and attest to active reworking by waves propagating from Notre Dame Bay. Curvilinear furrows and widespread pitting attest to frequent iceberg grounding, particularly along the south side of the bay within the 100 m isobath. A large iceberg was grounded in 30 m of water off Nickey's Nose Cove at the time of the beach survey in June 1992 (Edwardson et al., 1993b) and the resulting pit was observed on sidescan sonar imagery obtained from CSS *Parizeau* (cruise 92042) in October of the same year (Fig. 47, pit south of the site of sample 015).

During the coastal surveys of cruise 92301 (Edwardson et al., 1993b), hand-trowel samples were collected on beaches and Ponar grab samples were obtained offshore using small boats. Samples were collected near Jackson's Cove (samples 73–78), Nickey's Nose Cove (samples 58–64 and 121–123), Salmon (Upwards) Cove (samples 67–70), Burgess Cove (samples 65 and 66), and at Winterhouse Cove in Northwest Arm (samples 82 and 83). Large-volume IKU grab samples (samples 014–019) were obtained from CSS *Parizeau* (cruise 92042) in deeper water. Fourteen samples from cruises 92301 and 92042 were analyzed for gold using the method of M. Kuryluk and C.D. Raymond (unpub. rept., 1993), and results were reported by Edwardson et al. (1993a).

Three samples from Burgess and Upwards coves that were analyzed using method 2 of M. Kuryluk and C.D. Raymond (unpub. rept., 1993) showed elevated levels of gold ranging from 57 to 799 ppb. Visible gold grains were identified in samples from Upwards Cove and Nickey's Nose Cove. All sample locations had elevated levels of gold. Visible gold grains were found 11–15 km from the nearest known vein occurrence and 11–12 km from the nearest accessory gold-base metal deposit at the Little Bay mine site. This suggests concentration of gold by wave sorting on the inner shoreface and a possible association with gabbro or diabase intrusive rocks onshore in this area. Wave energy in Upwards Cove is particularly high as the cove opens northward and has a relatively steep profile, which enables refracted waves from Notre Dame Bay to penetrate well into the cove. The beach at this site consists of pebble- to boulder-sized material with the upper storm crest almost 6 m above mean sea level (Fig. 29), only slightly higher than the marine terrace behind the beach. Burgess Cove is partly protected by Green Bay Island; the beach is much lower and backed by a vegetated scarp defining the outer face of a marine terrace at about 5–6 m above present sea level. The gold found in nearshore sands at these two sites may have undergone multiple cycles of reworking in the nearshore zone when relative sea levels fell throughout the Holocene. In addition, the vegetated scarp at the back of the beach at Burgess Cove suggests a possible short-lived transgressive phase that has now ended.

Little Bay

Little Bay (Fig. 48) is one of a number of embayments on the coast of Notre Dame Bay between Baie Verte Peninsula and Bay of Exploits that are distinguished from the large fiords of the study region by their small extent, their relatively shallow depths, their high exposure to wave activity, and the high degree to which they are impacted by icebergs. The maximum water depth at the mouth of Little Bay is about 250 m. The bay shallows southward so that northwest of Beaver Cove Head, the maximum depth is 170 m. The coastline is predominantly steep and rocky, with small, scattered, gravel pocket beaches, commonly backed by raised beach deposits, as at Woodford Cove and Wiseman Beach. A fringing gravel beach is found at Long Beach on an otherwise steep coast; vertical cliffs extend from there to the end of the peninsula at Red Island.

Data from CSS *Navicula* cruise 90035 show a tongue of postglacial mud that extends into Little Bay from Notre Dame Bay and is confined to the deepest parts of the central trough. It overlies acoustically stratified, glaciomarine mud, which is exposed on the seabed in places where strong currents have prevented postglacial mud from accumulating. In areas away from the deep trough in Little Bay, bedrock is commonly exposed on the highly irregular seabed.

Small basins are partly or wholly filled with sediment that is mostly acoustically transparent, but that also contains scattered, weak, continuous, wavy, parallel, internal reflections. These deposits are up to 15 m thick and have an irregular upper surface with relief of several metres. This unit is interpreted as iceberg-turbated, glaciomarine sediment mixed with postglacial mud and ice-rafted gravel. Sidescan sonograms have a predominant dark tone with light-toned, circular, elliptical, or elongate mottles that are interpreted as iceberg pits with muddy infills surrounded by gravel berms. Some pits and berms have a subdued relief; others have fresh, sharply defined berms. Fresh furrows up to 20 m wide with multiple berms also occur.

Gold has been recovered from a mine in massive sulphide deposits at the head of Little Bay (Swinden and Baxter, 1984). However, no gold was found in the mud fraction or in a panned concentrate of the five samples analyzed (samples 142–150, even numbers). The sediment sources here are glaciomarine deposits reworked by icebergs, gravel rafted by sea ice, and miscellaneous minor sources, for example Little Bay River. The minor pockets of raised marine sediment exposed at the coast in this area would not be significantly reworked by waves in such a sheltered setting. The source of sediment to Long Beach may be unmapped pockets of raised marine sediment that may contribute sand and gravel to the littoral zone; Canadian Hydrographic Service (1980) Chart 4585 shows sand on the seabed landward of the area surveyed from the CSS *Navicula*.

In Little Bay, the wave-dominated seabed zone probably occurs landward of the survey area and is not as wide as off La Scie. Most of the survey area is similar to the outer zone off La Scie. Iceberg impact is clearly a major force in mobilizing sediments on the seabed. No deposits of glacial diamicton were identified. There are no extensive source deposits for placer gold and no mechanism for concentrating sediment. This region has a low potential for gold placers.

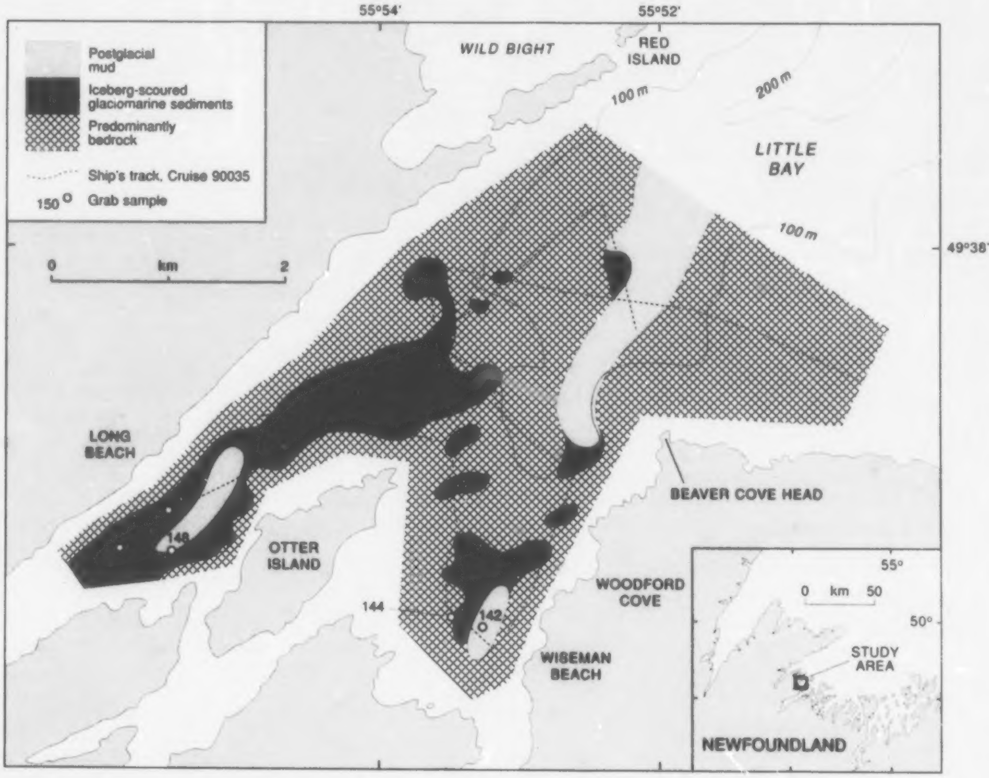


Figure 48. *Map of Little Bay showing ship's tracks for cruise 90035, grab-sample sites, and surficial sediments.*

Halls Bay

Halls Bay (Fig. 49) is a fiord 2 to 3 km wide, about 30 km long, and over 450 m deep off Sunday Cove Island. It shallows gradually to near Dock Point, then more sharply thereafter. A ledge lies off Springdale (above 180 m) and another, off Mansfield Cove. The bay contains ponded, Quaternary deposits that are up to 180 m thick in a narrow (0.5–1.0 km) ribbon along the thalweg of the bay (Jenner and Shaw, 1992). Their volume is approximately 5 per cent of the fiord volume below sea level. Their surface is at a depth of 450 m off Sunday Cove Island and 300 m off Springdale. The fiord sidewalls have slopes locally up to 50° and a discontinuous veneer of gravelly mud or muddy sand in shallow water close to the coast.

The Quaternary deposits are composed of stratified, glaciomarine sediments (unit 3) overlain by thin, ponded, postglacial mud (unit 4). The glaciomarine sediments are up to 170 m thick and contain acoustically transparent intervals up to about 20 m thick whose upper surfaces commonly show fine-scale (<0.5 m) roughness. In places, these transparent intervals pass abruptly into stratified deposits. They are interpreted as debris-flow deposits that accumulated in close proximity to ice standing at the head of the fiord and in side valleys. The glaciomarine sediments seem to be deformed towards the head of the fiord. At one location, a block of sediments 10 m thick and at least 800 m long has been detached. The internal reflections have been deformed by faulting and slumping; the degree of deformation increases southwest of Springdale so that internal reflections eventually disappear and the glaciomarine sediments have an irregular, hummocky surface with relief up to 10 m.

The ponded postglacial mud is typically about 10 m thick in Halls Bay, but thins to the southwest to only 1 m just southwest of Dock Point; beyond Dock Point, it is patchy and glaciomarine deposits are exposed on the seabed. Some of the surface irregularity in this area is attributable to modern iceberg pits and furrows that are found at water depths of less than 60 m, whereas the remainder is due to deformation in the glaciomarine sediments (*see* above). Where a thin (<2 m) layer of Quaternary sediments overlies fiord sidewalls, sidescan sonar records show a botryoidal pattern (Fig. 50) due to the occurrence of lobate creep terraces. Such terraces have been observed at the head of the bay, off Wolf Point, and off Springdale. Slopes at four sites ranged from 5° to 10°. Off Springdale, a bedrock ridge extends northeast from Green Island. The bedrock basin between the ridge and the mainland contains up to 10 m of acoustically incoherent sediment, interpreted as slumped, glaciomarine material. Steep (up to 10°) slopes have creep terraces.

Core 90013-063 was collected in a water depth of 246 m off Dock Point. The Huntec profile (Fig. 14) shows an uppermost, acoustically transparent unit about 1 m thick (postglacial mud) overlying 15 m of stratified, glaciomarine sediments with wavy bedding produced by a series of

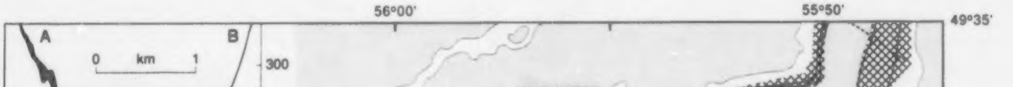


Figure 49. Map of inner Halls Bay showing sampling sites, surficial sediments, and seabed features. Inset at top left shows a cross-fiord profile near Springdale.

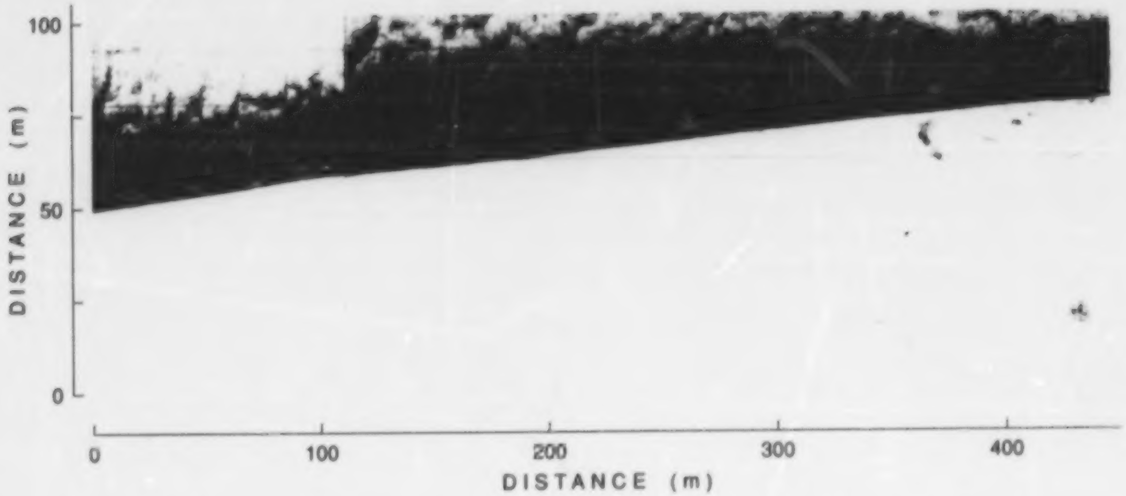


Figure 50. *Sidescan sonar record showing a botryoidal pattern on fiord sidewall sediments in Halls Bay, possibly attributable to creep. Cruise 90035, day/time 225/15:45–15:50.*

normal faults. These deformed sediments apparently rest on a slump plane overlying crudely stratified sediments. The core penetrated to 6.67 m. A bivalve at 4.00 m is dated at 11 330 ± 130 BP (TO-3170).

Raised ice-contact and ice-distal fan deltas at the head of Halls Bay have been mapped by various workers (Tucker, 1974; Scott and Liverman, 1991; Scott et al., 1991). The basinal, glaciomarine, gravelly muds in Halls Bay were deposited concurrently with the glaciomarine deltas in the area, at a time of falling relative sea level. The sandy delta foresets on land at Springdale are not seen offshore; rather, steep fiord walls have a small package of slumped, glaciomarine sediment trapped above the main sediment package in a perched basin. Similarly, thin and highly disturbed glaciomarine muds occur at the head of the bay.

Most samples collected during cruise 90035 are from the head of the bay and the shelving terrace off Springdale; they indicate that, away from the deep trough, the seabed comprises a thin veneer of postglacial mud with gravel derived partly from ice rafting and partly from the disturbance of the glaciomarine sediments by iceberg action. Samples 186 to 196 inclusive, taken at water depths of between 34 and 199 m, were poorly sorted and generally consisted of sandy, muddy gravel; the exception was sample 186, a muddy, fine sand recovered directly offshore (water depth 34 m) from a beach. Photographs show subrounded to angular gravel on a fine-grained sea bottom. Samples 198 to 204, collected off Springdale, are also poorly sorted and comprise muddy, sandy gravel. Photographs show poorly sorted, rounded to subangular gravel on muddy sand.

This area has low potential for gold placers. There is little gold onshore, wave energy is moderate to low, and relative sea level fell through much of the Holocene. In ten samples assayed from CSS *Navicula* cruise 90035 (samples 186–204, even numbers), gold concentrations were all below 10 ppb. If placer deposits were present in inner Halls Bay, they would occur in very shallow water close to shore. Littoral deposits include small deltas at the mouths of West Brook and South Brook (at the head of the bay) and a larger delta where Indian Brook debouches into the bay. Fringing gravel beaches extend for more than 5 km along the west side of the bay north of West Brook, more than 2 km across the head of the bay west of Wolf Head, and almost 5 km along the eastern shore north of South Brook. They are primarily derived from partly stabilized bluffs in Quaternary terrace deposits. A small barrier beach occupies the head of Wolf Cove (Fig. 32) on the east side of Wolf Head. Dock Point and another similar feature 1 km to the northeast along the western shore are small, sandy forelands.

Together, these features provide evidence for an interval of stable relative sea level in the late Holocene, as well as extensive wave reworking in a narrow band close to the present shoreline. The extensive, drift-aligned beaches and sandy foreland deposits along the western shore point to longshore transport by waves propagating up the axis of the bay. This suggests that, if appropriate source material were present in the terrace deposits, the highest potential for mineral concentration would be in beach deposits along the western shore near Dock Point and across the upper end of the bay west of Wolf Head.

Sunday Cove Island region

This region (Fig. 51) comprises a series of relatively sheltered embayments that open to Halls Bay to the north and connect east to Notre Dame Bay via Long Island Tickle (see Canadian Hydrographic Service, 1981a, 1993). At the

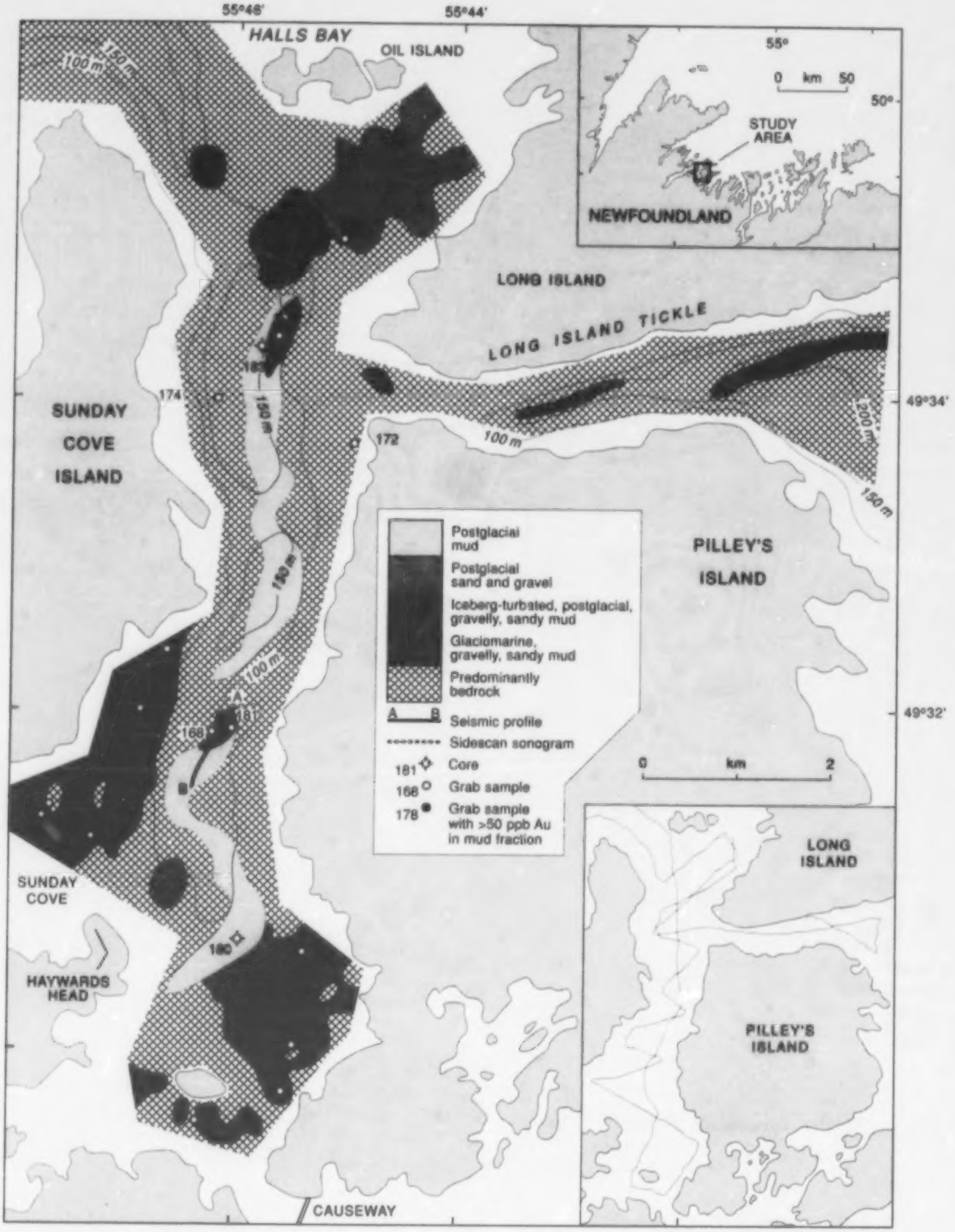


Figure 51. Map showing surficial sediments, grab samples, and gold content in the Sunday Cove Island region, as well as the location of the seismic record illustrated in Figure 52 and the sidescan sonogram shown in Figure 53. The inset at bottom right shows ship's tracks for cruise 90035.

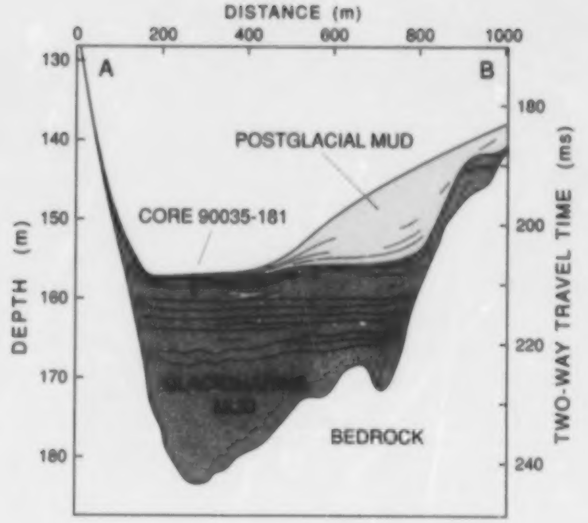


Figure 52. *Seismic record of banked, postglacial mud in the Sunday Cove Island area, showing the location of core 90035-181. Location of profile shown in Figure 51.*

northern boundary of the region, Halls Bay has a maximum recorded depth of 490 m. The channel extending south into the study region is much shallower (about 150 m) and leads to several basins. The largest basin lies due west of the entrance to Long Island Tickle and has a maximum depth of 187 m. A smaller basin just south of the main basin has a maximum depth of 179 m. Long Island Tickle is 73 m deep at its western entrance and deepens eastward to 243 m at the limit of coverage (cruise 90035). A channel extending west from Sunday Cove and connecting with Halls Bay is only 4 m deep at low tide and the passage of water is further constrained by a causeway.

The basins in the Sunday Cove Island region contain narrow, ponded deposits of stratified, glaciomarine sediment up to 40 m thick. Some glaciomarine sediments (e.g. in Long Island Tickle) are exposed on the seafloor, but most are overlain by postglacial mud up to 12 m thick. In several places, the postglacial mud is banked against one flank of the basin (Fig. 52), so that glaciomarine sediments are exposed on the basin floor.

Extensive bedrock outcrops occur over large areas. A sediment veneer of postglacial sand and gravel occurs near Oil Island, where the seabed is relatively exposed to wave action; elsewhere, valleys and depressions contain pockets of either postglacial mud or glaciomarine mud up to 20 m thick. Their distribution corresponds with that of a highly distinctive pattern observed on sidescan sonograms (Fig. 53) that consists of dark areas (gravelly mud or

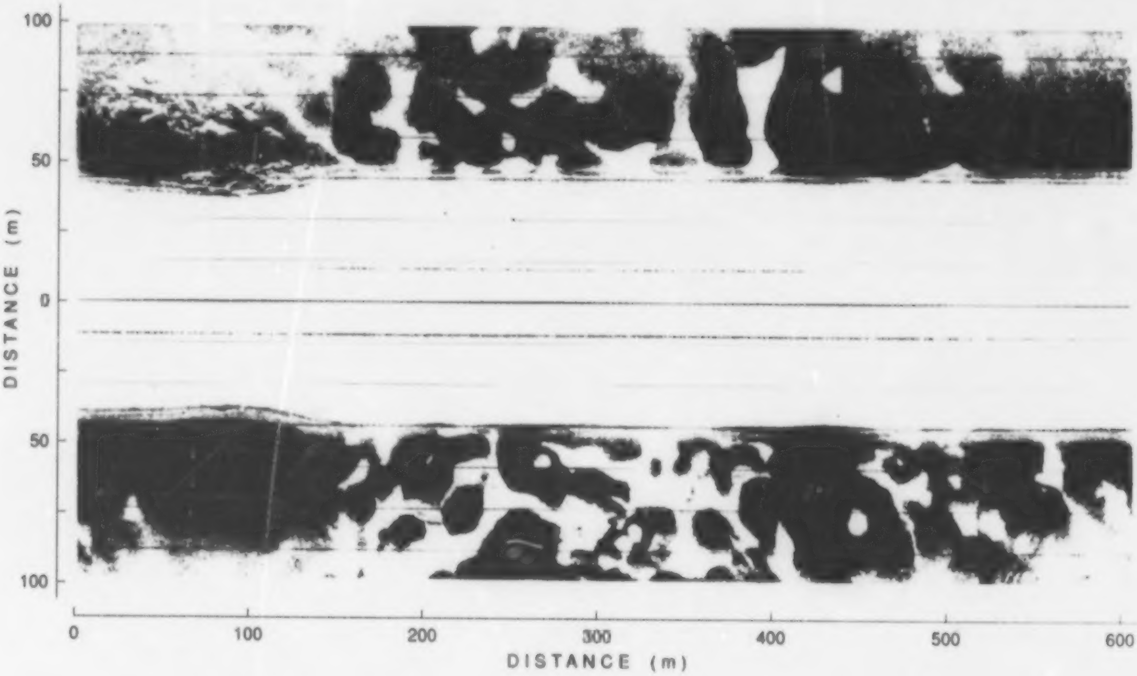


Figure 53. *Sidescan sonogram (location shown in Figure 51) showing iceberg-impacted seabed in the Sunday Cove Island area. Cruise 90035, day/time 227/14:55–15:00.*

gravelly sand) surrounding circular, elliptical, or elongate light areas. These light areas are depressions formed by grounding of the icebergs that drift into the region in summer. The light tones represent a fill of mud or muddy sand. The icebergs seem to ground at the south and north ends of the embayments, perhaps drifting from one end to the other with wind and tide.

Each of four gravity cores collected in this area (cruise 90035) penetrated veneers of postglacial mud (unit 4) to intersect underlying glaciomarine sediments (unit 3), typically clay with angular grit and pebbles. In core 180, bivalves in unit 4 are dated at 8250 ± 80 BP (TO-2398) and 8870 ± 80 BP (TO-2397), from which it is inferred that the unconformity separating units 4 and 3 postdates 8.9 ka. In core 181, a bivalve in unit 4 is dated at 6050 ± 70 BP (TO-2396). The core contained 0.04 m of gravelly sand at the unconformity between units 4 and 3. In core 183, a bivalve in unit 3 is dated at 11 600 ± 80 BP (TO-2395). Thus, unit 3 was deposited concurrently with the glaciomarine delta deposits of inner Halls Bay, whose ages are in the 11–12.5 ka range (*see* previously cited references).

Most grab samples collected in this area comprise muddy, sandy gravels, typically 70 per cent gravel, 20 per cent sand, and 5 per cent mud. The gravel is angular to subangular. Only two samples, 172 and 178, both from the more exposed northern part of the region, contained gravel with encrusting *Lithothamnion* sp. The photograph of the seabed taken near the site of sample 152 shows angular gravel on a muddy sand bottom. The photograph taken near the site of sample 154, which was mostly gravel, shows a fine, muddy sand bottom with numerous tracks and no gravel. It was taken in an area of intense iceberg pitting, possibly at the bottom of a pit. The same applies to the photograph taken near the site of sample 156. Most other photographs show angular gravel, often thinly coated with mud, on a fine-grained seabed. Anemones are commonly attached to clasts. However, the photograph taken near the site of sample 166 shows an angular boulder 1.1 m in diameter. Worm tubes are seen in sample 168, collected from a basin where very thin mud veneers glaciomarine sediment.

Gold was found in only one sample in this region, at a concentration of 64 ppb in mud from sample 178, collected near Oil Island (Emory-Moore, 1991). This is not surprising, since there are few sources of gold onshore: gold has been recovered from Miles Cove, but not from the volcanogenic sulphide deposit at Pilleys Island mine (Emory-Moore, 1991). Also, there are no extensive seabed or coastal exposures of glacial diamicton that could be reworked by waves to concentrate gold. Neither are there sources of fluvial sediment. The angular gravel that commonly lies on the seabed is probably derived from ice rafting. Wave action is very limited in this area, except for the shallow shelf in the northeast, close to Oil Island (although the seabed is highly disturbed by icebergs and tidal currents), and no significant sediment source and no mechanism exist to concentrate significant amounts of gold into placer deposits. This region has a low potential to host placer gold.

Wild Bight

The purpose of the survey of Wild Bight (Fig. 54) was to examine the seabed offshore from a rugged, rocky, outer-coast environment. Wild Bight lies on the northeast side of Long Island, between Seal Island and Southern Head. Navigational constraints, including position errors on the charts, restricted survey and sampling operations to the inner-shelf area depicted in Figure 54. The coast is rocky and almost completely devoid of beach sediment. Nearly vertical cliffs up to 75 m high are present along the southern shore of Wild Bight and steep rock slopes up to 100 m high are found at Bread and Cheese Cliff. Rock cliffs are also present on Seal Island, which has a single, small crevice beach. All other island shores shown in Figure 54 are rocky, but numerous small gravel beaches and boulder flats are present outside the map area on more protected shores on the northwest corner of Long Island.

A steep-sided channel extends eastward from Wild Bight, deepening from 100 m water depth about 1 km north of Indian Island to over 250 m within 0.6 km of Bread and Cheese Cliff. The inner shelf north of this channel and east of Seal Island slopes seaward from less than 50 m along the western margin of the survey area to over 100 m in the channel between Seal Island and the Burnt Islands to the north. It deepens to about 150 m at the outer end of a broad ridge extending east along the north side of the southern channel described above, to about 1.5 km north of Southern Head and to about 200 m off the Duck Islands in the north. A buried channel extends east and northeast from the passage north of Seal Island.

Whereas the southern channel off Southern Head has virtually no sediment, the northern channel is almost completed filled and has no significant surface expression. The northern flank of the southern channel is dominated by rock outcrop; the steep slope on the south side of the channel below Bread and Cheese Cliff is probably also rocky. Exposed rock extending north from Seal Island and south from the Burnt Islands may connect across the intervening channel. Other scattered outcrops occur throughout the survey area.

Most of the area is covered by a veneer of gravelly sand (locally muddy) and coarse cobble-boulder gravel. The sidescan imagery shows no wave-formed bedforms in these sediments. Fine-grained sediments interpreted as Holocene mud or muddy sand overlying stratified deposits interpreted as glaciomarine, sandy (locally gravelly) muds are present in the buried channel south of Duck Island in water depths of 150 to 200 m, and in small basins on the seaward slope of the inner shelf in depths over 250 m. Sidescan sonograms off Wild Bight show almost ubiquitous mottling associated with reworking of the seabottom by icebergs. Some furrows and pits were more sharply defined, indicating relatively recent iceberg grounding. A good example is the furrow whose location is indicated in Figure 54; it was 150 m long, 25 m wide, and at a water depth of 60 m. Iceberg furrows and pits were found in water depths ranging from 50 to 150 m, preferentially on north- and northeast-facing slopes and on the summit of the ridge extending southeast from Seal Island.

Six IKU grab samples and accompanying photographs of the seabottom were collected from the CSS *Parizeau* in 1992. The samples and photographs (Fig. 55) are described in detail in order to illustrate the extreme patchiness of the seabed and the occurrence of coarse-grained, surficial layers overlying finer material.

Grab sample 34 (water depth 103 m) was an olive-grey, silty sand with worm tubes, scattered angular pebbles, and a surficial veneer of coarser sand. Two of the four seabottom photographs taken near the site of the sample show a smooth surface with scattered shell fragments and faint ripples. The other two photographs (one is Figure 55a) show subangular to angular gravel clasts with a veneer of finer sediment, perhaps muddy sand. The sidescan sonogram from this area shows a predominantly light-toned seabed with scattered patches of gravel. This area is an iceberg-impacted zone.

Grab sample 36 (water depth 97 m) had a surficial layer of subrounded to subangular pebbles and cobbles, as well as a layer of coarse, shelly sand overlying medium to fine sand. Photographs of the seabottom show a pavement of subangular to subrounded gravel with a few boulders; Figure 55b shows gravel adjacent to bedrock outcrop. The sonogram shows a rough, dark-toned (highly reflective) seabottom.

Grab sample 38 (water depth 86 m) contained a surface layer of pebbles and cobbles that were encrusted on the sides and top with coralline algae and barnacles. The gravel layer overlies poorly sorted, muddy, medium to coarse sand with shell hash. Of the five seabottom photographs taken at this site, three show a fine-grained surface, one shows the surficial gravel layer (Fig. 55c), and one shows a large,

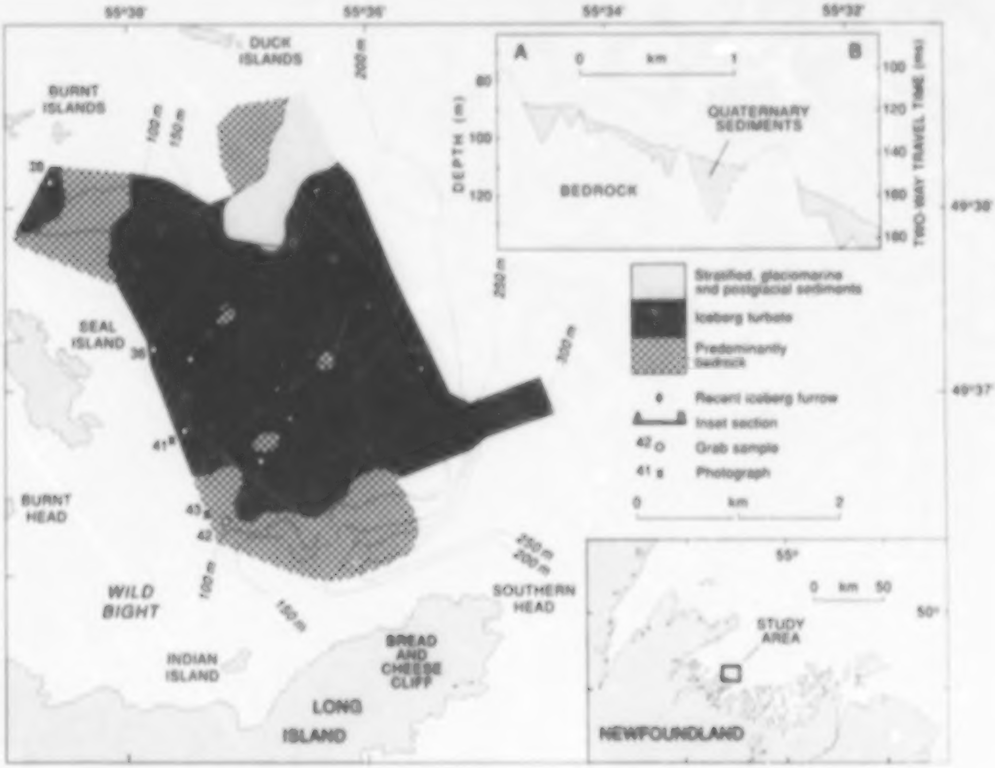


Figure 54. Map showing the location of surficial sediments and grab samples in Wild Bight. The inset at top right shows the thickness of Quaternary sediment along line AB.

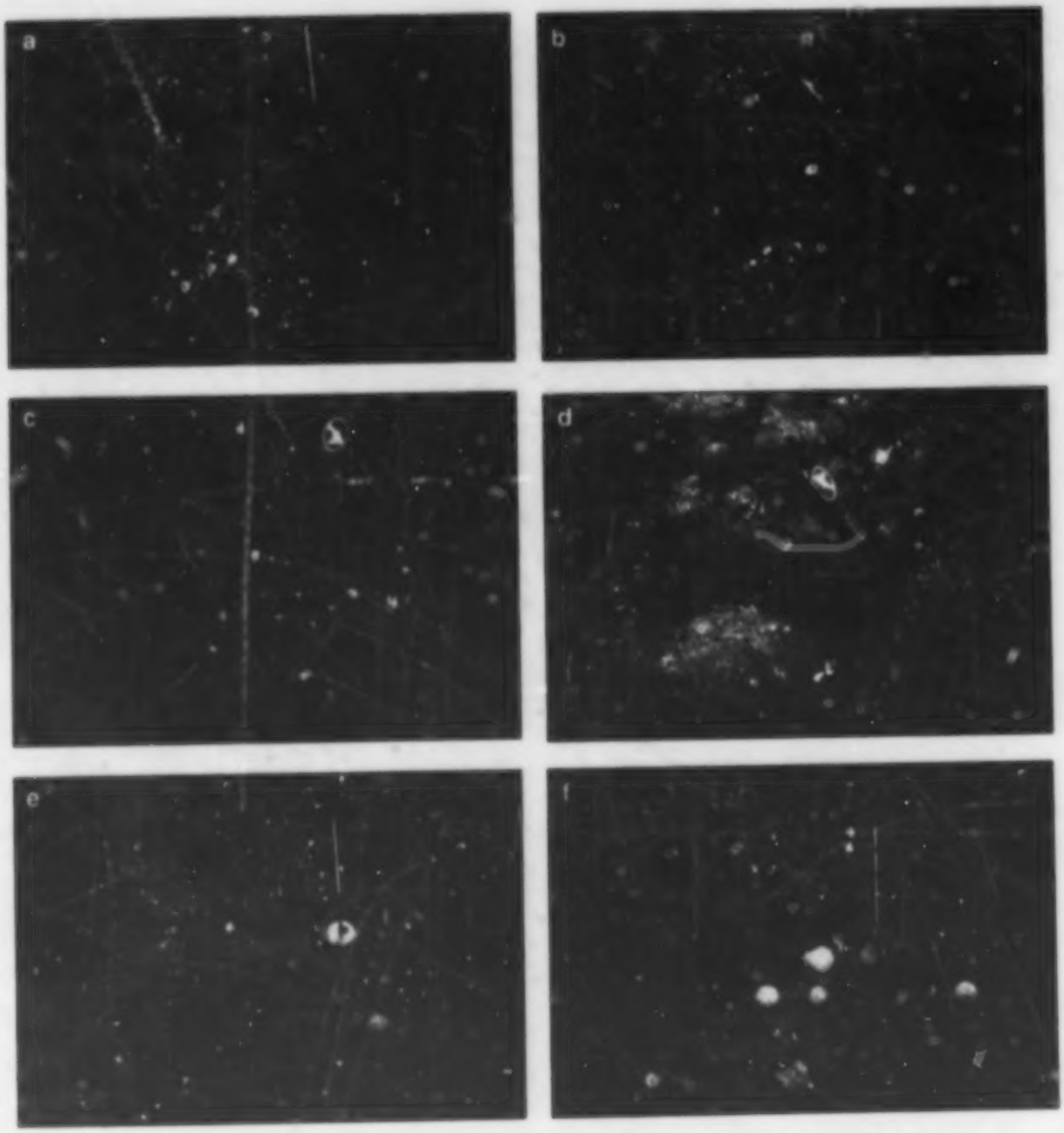


Figure 55. *Six bottom photographs from Wild Bight;* ***a)*** *was taken near the site of grab sample 92042-034 (GSC-056A),* ***b)****, near the site of grab sample 92042-036 (GSC-056B),* ***c)*** *near the site of grab sample 92042-038 (GSC-056C),* ***d)****, near the site of grab sample 92042-040 (GSC-056D),* ***e)****, near the site of grab sample 92042-042 (GSC-056E), and* ***f)****, near the site of grab sample 92042-044 (GSC-056F).*

angular boulder. The sonogram taken at the sampling site shows a dark-toned seabottom with lighter mottling (iceberg pitting) and nearby bedrock outcrops.

Grab sample 40 (water depth 81 m) contained a surface layer of gravel, including a subangular boulder, overlying poorly sorted, muddy, fine-medium sand with shell hash. Five photographs showed a bedrock seabottom littered with gravel (Fig. 55d). The sonogram shows a bedrock ridge covered with gravel (dark tone), with finer sediment in valleys.

Grab sample 42 (water depth 97 m) failed to trip on four attempts; the fifth attempt produced muddy, gravelly, fine sand with calcareous worm tubes. The four seabottom photographs (water depth 55 m) were not taken at the sampling site; they show subangular to angular gravel (Fig. 55e). The sonogram shows a bedrock ridge mostly covered with gravel (dark tone) and with finer (light tone, dark mottling), iceberg-turbated sediment in depressions.

Grab sample 44 (water depth 80 m) contained fine-medium, well sorted sand with scattered shell fragments. Eight seabottom photographs taken in 66 m water depth show angular to subangular, boulder-cobble gravel (Fig. 55f). The sonogram shows a predominantly dark-toned (gravel) seabottom with iceberg pits and finer sediment in depressions and on the floors of iceberg furrows.

Negligible levels of gold were detected in the six samples (Edwardson et al., 1993a), although a heavy-mineral concentrate of sample 42 contained one flat, folded gold grain with a long-axis length of 215 µm.

Badger Bay

Badger Bay (Fig. 56) is intermediate in size between the major fiords (Green Bay, Halls Bay, or Bay of Exploits) and lesser embayments such as Little Bay or Ming's Bight. The survey was done at a reconnaissance scale only, limited to deep water. No grab samples were collected, so there is no information regarding gold content.

The bay has a maximum depth of 525 m and bifurcates off Duck Island. The south-trending channel has depths exceeding 350 m. The channel immediately north of Duck Island is 180 m deep and shallows towards the southwest. Troughs in Badger Bay contain stratified, glaciomarine

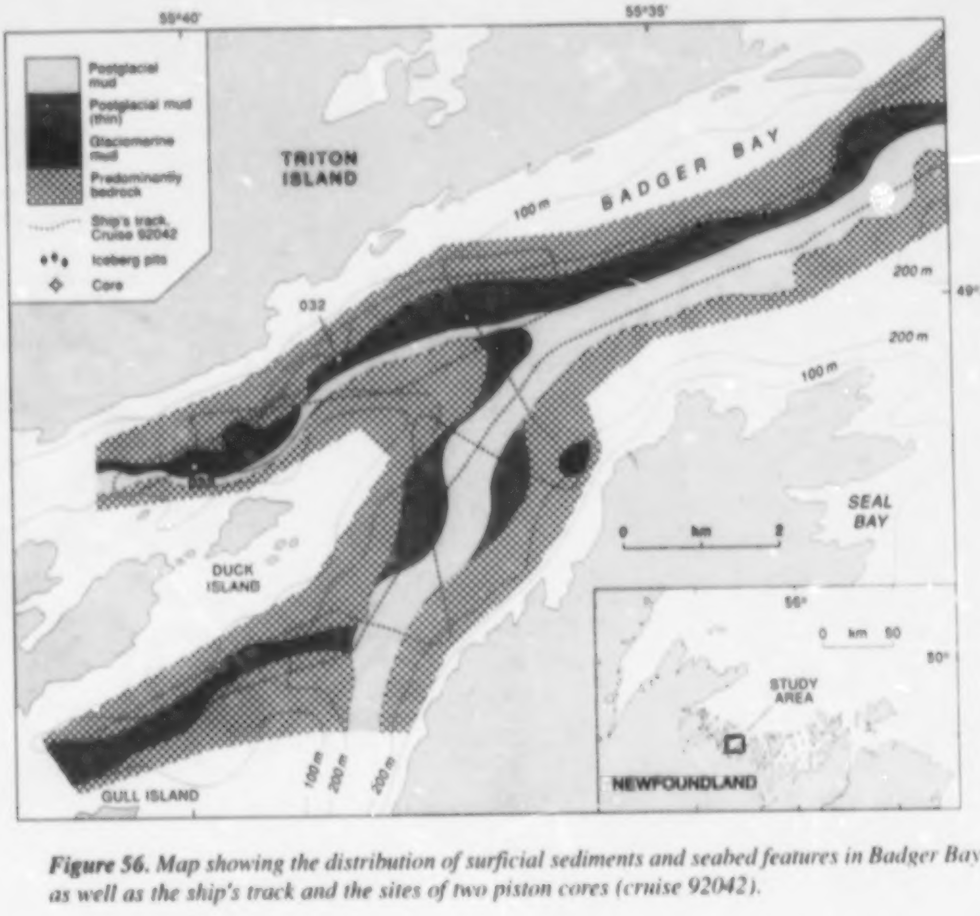


Figure 56. Map showing the distribution of surficial sediments and seabed features in Badger Bay, as well as the ship's track and the sites of two piston cores (cruise 92042).

sediments that are 110 m thick northeast of Duck Island. These glaciomarine sediments contain interbedded, acoustically transparent intervals that are characteristic of the deep, glaciated, coastal basins elsewhere in the region. Ponded postglacial mud, typically about 20 m thick, overlies glaciomarine sediments in the basins and also occurs as a 2–5 m thick veneer over the irregular bedrock slopes on the basin flanks. Towards the heads of the arms, the postglacial mud occurs in banks, so that the underlying glaciomarine sediments are exposed on the seabed. North of Gull Island, in water depths of 100 to 130 m, the seabed has a relief of several metres and the sediments (<10 m thick) are acoustically opaque. This may be an area of iceberg grounding and iceberg turbate formation, comparable to those areas observed in Little Bay, the Sunday Cove Island region, and Wild Bight.

Core 92042-032 (water depth 267 m) intersected unit 3 sediments that were likely deposited by meltwater plumes discharged from ice located at the head of the bay. Radiocarbon ages on shells are 12 010 ± 90 BP (TO-3859) and 12 420 ± 90 BP (TO-3855). As noted earlier, the coring system malfunctioned during collection of core 92042-033. The Huntec profile at the core site shows 0.5 m of unit 4 overlying unit 3. The presence of well sorted sand in the core barrel is intriguing and may indicate that strong tidal currents winnow the seabed in the area.

New Bay

The survey of New Bay (Fig. 57) was also done at a reconnaissance scale, with no grab samples and only one core. New Bay is comparable in size to Badger Bay. It has a bedrock sill at a water depth of 200 m and an axial trough with a maximum depth of 439 m. Steep bedrock sidewalls with a discontinuous veneer of mud or gravelly mud flank a central basin that contains ponded, postglacial mud overlying basin-fill, stratified, glaciomarine sediments. Postglacial mud (unit 4) is banked to one side of the basin near the head of the bay, so that glaciomarine sediments (unit 3) are exposed on the seabed (*see* inset section, Figure 57). Core 92042-012 (water depth 228 m) penetrated

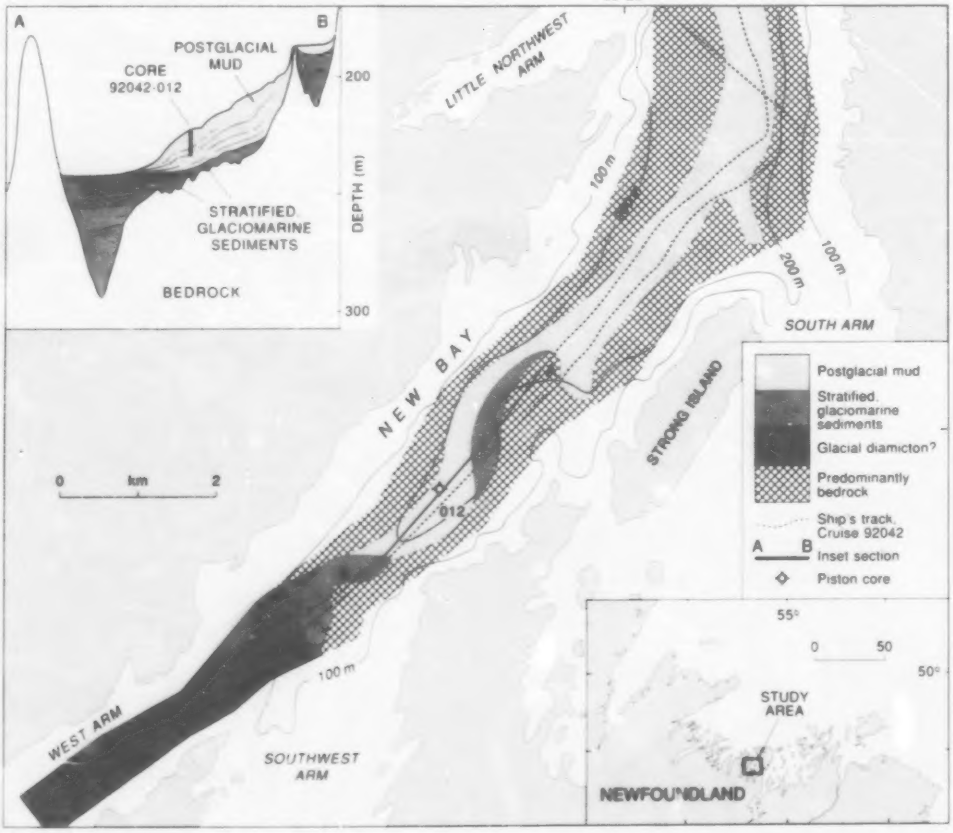


Figure 57. *Map showing the distribution of surficial sediments in New Bay, as well as the ship's track and the site of a piston core (cruise 92042). Inset at top left shows interpretation of a Huntec profile along line AB.*

banked deposits of unit 4 (Fig. 57). The uppermost 7.21 m of the core is bioturbated, grey to olive-grey mud (unit 4) containing bivalve samples from 0.63, 4.45, and 7.11 m that are dated at 5980 ± 60 BP (TO-3857), 9210 ± 80 BP (TO-3858), and 11 470 ± 80 BP (TO-3854) respectively. At the bottom of the core is a unit (7.21–8.76 m) of bioturbated, butter-like, grey clay with grit and angular pebbles (unit 3). At the head of the bay, a zone of acoustically incoherent material 20 m thick may be either glacial diamicton or, as at Halls Bay, glaciomarine, gravelly mud, formerly stratified, but now disturbed by slumping.

Bay of Exploits

Bay of Exploits (Fig. 10) is a complex of bays with two principal channels, both over 600 m deep and separated from one another by an area of shallow (<100 m) water with numerous islands and shoals. Both principal channels contain ponded deposits of postglacial mud overlying stratified, glaciomarine mud. The western channel (Fig. 58) has a maximum depth of 673 m and extends southward from a bedrock sill at about 210 m water depth. The Exploits River, which has a drainage basin area of 11 400 km^2 and a mean annual discharge of 262 m^3·s^{-1} (Hydrology Consultants Limited, 1980), empties into the head of the bay.

Ponded Quaternary sediments are found in a narrow (1 km) trough bounded by fiord sidewalls with slopes up to 70°. Total sediment thickness decreases southward from 200 m just south of Exploits Islands (Fig. 10) to 70 m at the south end of Thwart Island. The thickness of postglacial mud is markedly reduced towards the head of the bay. The Quaternary sediments (Fig. 10) apparently record the intermittent southward retreat of Late Wisconsinan ice. The most northerly ice-halt position may be marked by a 40 m thick submarine moraine composed of acoustically incoherent sediment (unit 2) near Indian Cove. It is buried under stratified sediments (unit 3) and has no expression on the seabed.

A later ice margin was located at Porterville, where a prominent ridge of acoustically incoherent sediment 80 m thick and with a crest at a depth of 180 m extends across the bay. To the north, the ridge passes laterally into a seaward-thinning wedge of acoustically stratified sediments interbedded with acoustically transparent intervals (debris flows). These deposits are overlain by a wedge of acoustically incoherent sediment with a hummocky upper surface, which we think was formed by a submarine slide that propagated northward, away from a former ice grounding line. The slide sediment is overlain by stratified, glaciomarine mud and a veneer of postglacial mud. The glacial deposits off Porterville have not been dated, but are older than a shell dated at 11 480 ± 100 BP (Beta-51674/ETH-9469) from core 91026-010 (water depth 212 m) and a shell dated at 12 020 ± 100 BP (Beta-51672/ETH-9467) from core 91026-009 (water depth 82 m). D.R. Grant (pers. comm., 1993) has suggested that the ridge be informally termed the 'Porterville moraine'; the adjacent settlement of Porterville is built on large deposits of ice-contact, stratified drift with ice-push contortions.

A bedrock ridge extending across the bay at Phillips Head shallows to a depth of 9 m and has about 40 m of acoustically incoherent sediment (unit 2) on either flank. The presence of marine outwash at nearby Lower Sandy Point, graded to the local marine limit at about +50 m (D.R. Grant, pers. comm., 1993), confirms that the retreating ice was pinned there for a time. The basin between Phillips Head and the Porterville moraine contains ponded, stratified sediments up to 60 m thick, of which only 1–2 m appear to be postglacial. The basin southwest of Phillips Head contains about 50 m of stratified, glaciomarine sediments overlain by very thin, postglacial sediments on the west side, but by thicker (up to 5 m), postglacial deposits on the east side. Postglacial mud is about 3 m thick at the site of core 91026-009; a shell at 0.65 m down-core is dated at 3080 ± 60 BP (Beta-51670/ETH-9465). Also in core 91026-009, a shell at 3.56 m in stratified, glaciomarine sediments is dated at 11 440 ± 100 BP (Beta-51671/ETH-9466) and shell fragments at 4.23 m in the same unit are dated at 12 020 ± 100 BP (Beta-51672/ETH-9467). The acoustic horizons containing these samples postdate the morainal deposits at Indian Cove Island, Porterville, and Phillips Head, but are apparently approximately coeval with the upper part of the glaciomarine sediment deposited in Northern Arm.

In Northern Arm, just offshore from Botwood, up to 20 m of unit 3 are draped over irregular bedrock terrain with relief up to 10 m; steep slopes on the irregular bottom have creep terraces similar to those observed in Halls Bay. Above 45 m water depth, the seabed has been impacted by icebergs. At the mouth of the Exploits River, an extensive, gently sloping terrace with a lip lies at 6.1 m below mean water level. It is interpreted as a delta formed when sea level was about 6 m below the present level (Shaw and Forbes, 1995) and subsequently submerged.

In terms of its Quaternary history, the Bay of Exploits shares some characteristics with other fiord basins in the region, in particular the presence of steep, rocky side walls and deep, elongate basins containing thick, Quaternary deposits. The chief difference is the occurrence of cross-valley moraines formed when Late Wisconsinan ice halted during its southward retreat. No samples were analyzed for gold.

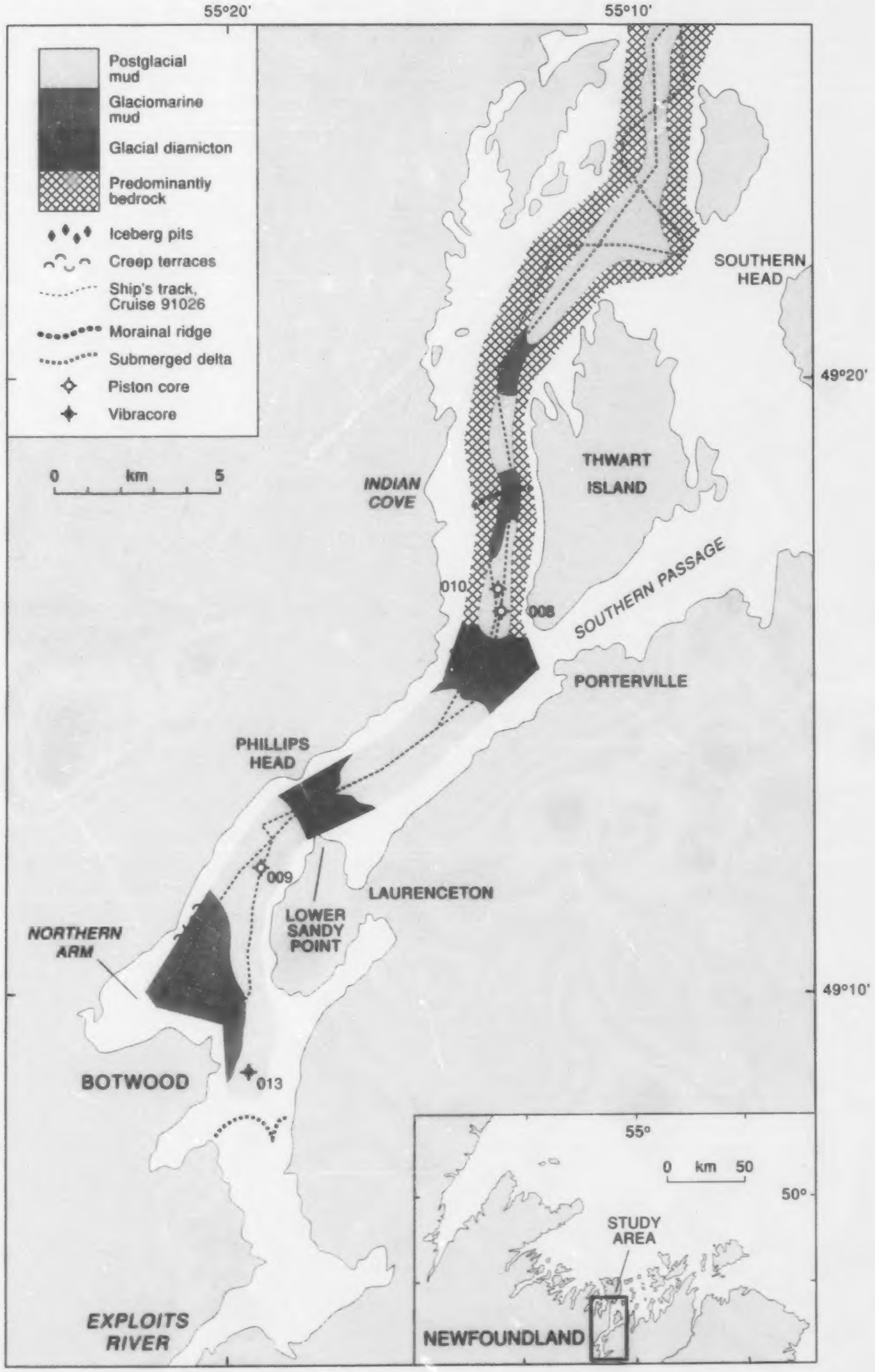


Figure 58. *Map showing the distribution of surficial sediments and seabed features in the Bay of Exploits, as well as ship's tracks and sites of grab samples and cores (cruise 91026).*

New World Island region: Twillingate and Moreton's Harbour

This region (Fig. 59, 60) comprises a series of islands and exposed embayments bordering the eastern margin of Notre Dame Bay and opening northward to the Atlantic. Moreton's Harbour, located southwest of Twillingate on the north shore of New World Island, deepens to 53 m at its entrance (Fig. 59). Wild Bight deepens progressively to 46 m at its centre and shallows to 33 m at its mouth. Farther east, Webber Bight is a less restricted embayment that opens northwestward and is confined to the north by Berry Island. It deepens to 48 m towards its southern margin at the entrance to Notre Dame Bay.

The dominant seabed texture between Webber Bight and Bear Gulch (Fig. 59) is postglacial gravel and muddy gravel with basins of ponded sand and mud up to 32 m thick, seaward of Moreton's Harbour and within Wild Bight, and up to 15 m thick in Webber Bight. Numerous iceberg pits have been identified, primarily in gravel, and ubiquitous sand ripples characterize the ponded sand and mud within Webber Bight. The basin in Wild Bight contains 10 m of acoustically stratified, glaciomarine sediment (unit 3) overlain by 10 m of acoustically transparent, postglacial sand and mud (unit 4). The shallower entrance to the bight is a bedrock sill with a gravelly mud veneer. Farther to the west and south, bedrock highs become more prevalent and the seabed texture is dominated by a veneer of postglacial, muddy gravel with rare, isolated sand patches. Ponded deposits are less common in this region than to the north and range up to 13 m thick. The seabed north of Big Gull Island contains patches of gravel ripples.

Twelve grab samples (91031-054 to 91031-076, even numbers) and ten seabed photographs (91031-55 to 91031-63, 91031-69 to 91031-71, 91031-77 to 91031-79, odd numbers) were taken. Postglacial gravel and muddy gravel commonly occur as a surficial (one to two pebbles thick) gravel veneer, partly encrusted with the coralline alga *Lithothamnion* sp., overlying sandy or muddy sediments. Where the sediments are sandy or muddy (samples 91031-64 and 91031-66, Wild Bight, and 91031-68, Webber Bight), the seabed photographs (91031-67 and 91031-69) show a soft seabed surface with scattered pebbles and disseminated shell hash. One hand-trowel sample taken on the

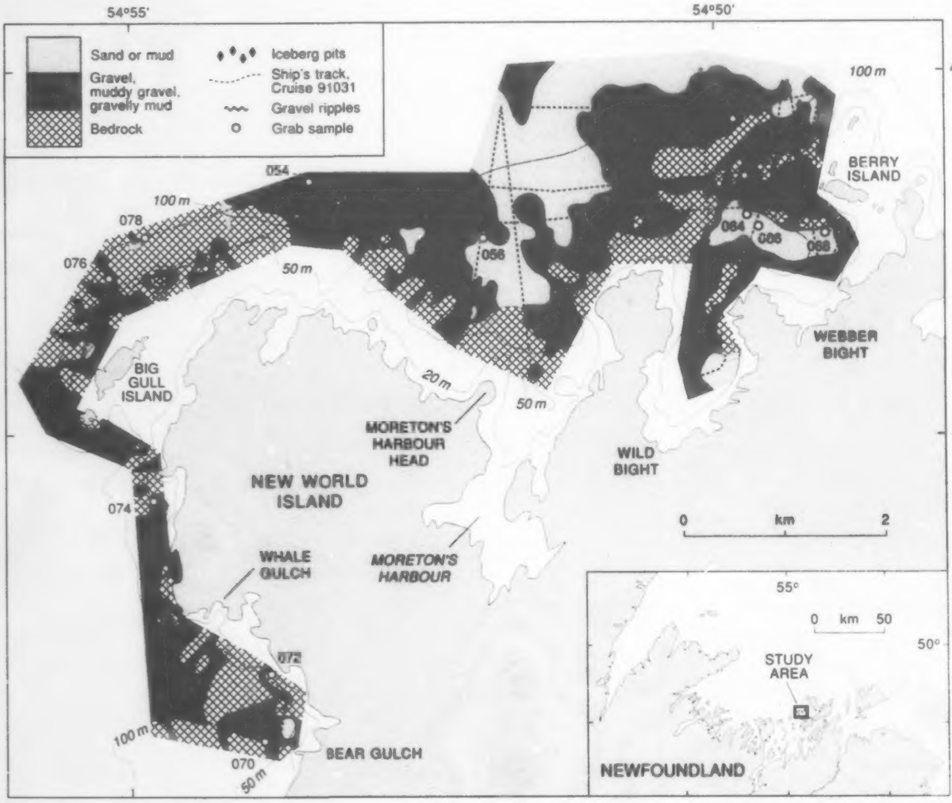


Figure 59. *Map showing the distribution of surficial sediments and seabed features off the northwest coast of New World Island, as well as ship's tracks and grab sample sites (cruise 91031).*

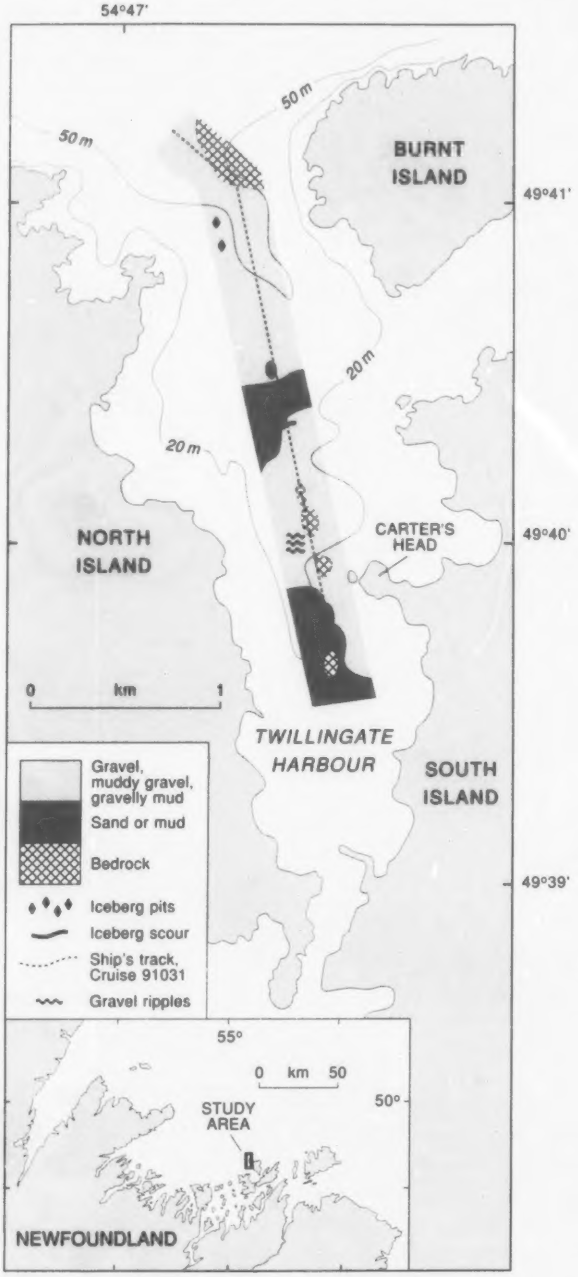


Figure 60. Map showing surficial sediments, seabed features, and ship's tracks (cruise 91031) in Twillingate Harbour.

beach at Webber Bight (92301-120) consisted of poorly sorted, fine to medium sand and granules with detrital shell debris.

Twillingate Harbour (Fig. 60) deepens progressively to 49 m at its mouth. Towards its head, the seabed consists of sand or mud with an outcropping bedrock high. Farther northward, past Carters Head, the predominant seabed texture is gravel with small sand or mud patches and isolated bedrock highs. Iceberg furrows occur within sand or mud along the contact between sand and gravel.

Eleven seabed samples from cruise 91031 and one beach sample from survey 92301 were analyzed for gold. Most samples contained less than 5 ppb Au in the mud and sand fractions; samples 91031-56, 91031-60, and 91031-72 contained 13, 15, and 9 ppb Au respectively. Two of the twelve samples (91031-068, Webber Bight, and 91031-070, Bear Gulch) contained visible gold grains. All samples were collected in a high-energy setting within 1 km of a known epigenetic gold occurrence on land; the two gold grains retrieved were heavily abraded and chemically etched (Emory-Moore, 1991). This region has a low to medium potential to host placer gold.

Dog Bay and Gander Bay

These bays (Fig. 61) differ considerably from embayments farther west in that they are relatively shallow and contain no deep, glacially overdeepened basins or thick deposits of glaciomarine sediments. They are funnel-shaped bays whose outer parts are exposed to high levels of wave activity. Several small streams drain into Dog Bay and the Gander River drains into Gander Bay. Gander River has a drainage basin area of 5200 km^2 and a mean annual discharge of 129 m^3·s^{-1} (Hydrology Consultants Limited, 1980).

The bathymetry of Gander Bay and Dog Bay (Fig. 61) was based on an old chart surveyed in 1869–1871 (British Admiralty, 1908) and is not considered highly reliable. The east coast of Dog Bay is predominantly rocky, with gravel pocket beaches (e.g. just north of Horwood; Edwardson et al., 1993b). From Horwood to the head of the bay, pebble and cobble beaches lie behind wide intertidal flats. The delta at the head of Dog Bay has extensive flats of pebbly, sandy mud strewn with boulders organized into polygonal 'garlands' (*see* Forbes and Taylor, 1994). An inactive boulder barricade was identified there. On the west side of Dog Bay, small pebble and cobble pocket beaches occur along the length of the predominantly rocky shore. Low eolian dunes are present at the south side of the sandy beach at Hunts Cove and a raised marine terrace several metres high is found just inland.

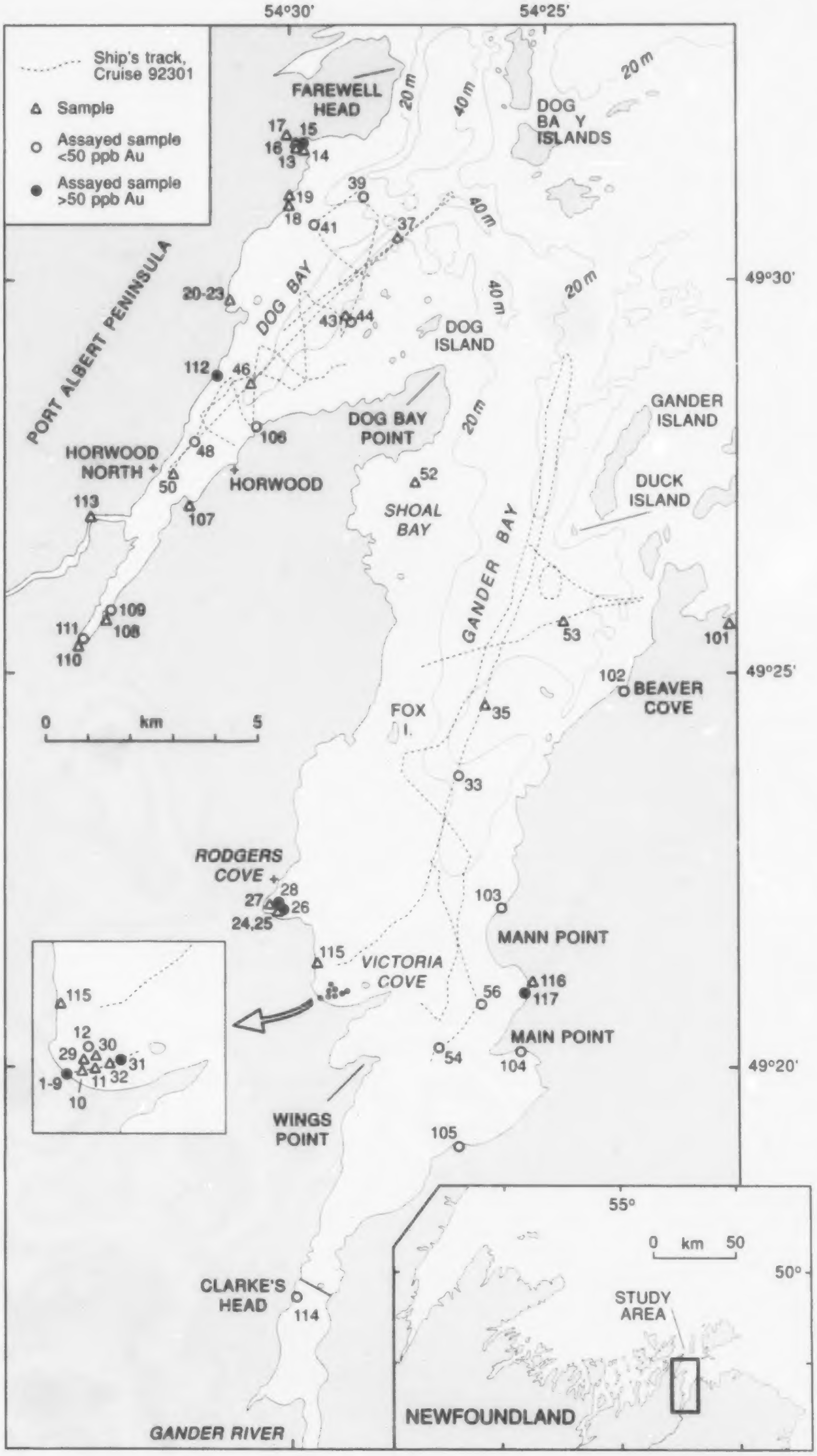


Figure 61. Map of the Dog Bay–Gander Bay region showing ship's tracks, grab sample sites, and assay results (cruise 92301).

A 50 m deep channel just west of the Dog Islands (Fig. 62) shallows northward to a sill at a water depth of 22 m. Postglacial sediments up to 11 m thick range from sandy silt towards the head of the bay and in deep water, to silty sand in shallower water and close to the coast. All samples contained subangular to angular pebbles in varying proportions. Photographs of the seabed show that the gravel lies on the surface of the finer sediments.

In Gander Bay, the west coast as far south as Fox Island has numerous pebble-cobble pocket beaches that constitute about 40 per cent of the shore. Farther south, the coast is predominantly low and rocky with mixed sand and gravel beaches and wide, sandy intertidal flats at Rodgers Cove and Victoria Cove (Fig. 61). Along the east side of the bay, near the causeway, boulder-strewn tidal flats front a low, rocky shoreline. North of there, the coast remains predominantly rocky, but wide intertidal flats and mixed sand and gravel beaches are found just south of Main Point and Mann Point, and at Beaver Cove. Just north of Mann Point, the wide intertidal flats backed by a gravel beach are replaced by a boulder-strewn rock platform. A northward increase in wave energy is evidenced by the presence of cobble-boulder beaches at Frederickton (Fig. 62).

Gander Bay gradually deepens northward to 33 m at its mouth (between Dog Bay Point and Gander Island). A central channel that extends northward between Dog Bay Islands and the mainland lies about 30 m below the surrounding seabed. Drumlins occur at the mouth of Gander Bay, near Gander and Duck Islands; they have a maximum relief of 7 m and are contiguous with those observed in Hamilton Sound (*see* below). They have a surficial veneer of muddy, subangular to angular gravel, in contrast to the

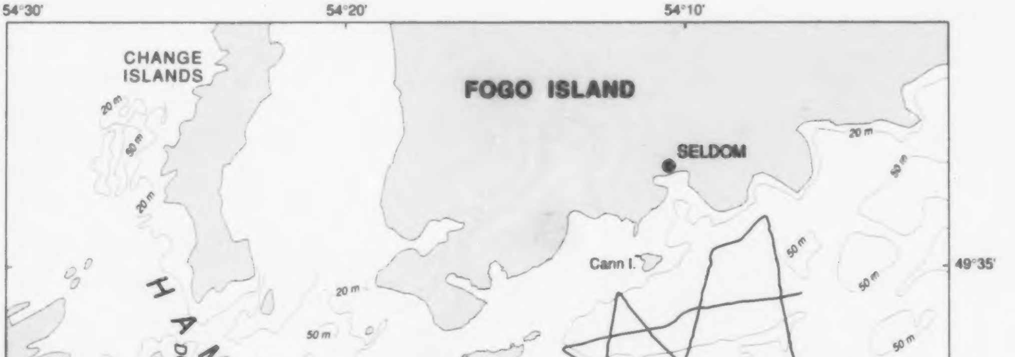


Figure 62. *Map of Hamilton Sound showing ship's tracks for cruise 90035 and the location of data illustrated in Figure 64.*

surrounding seabed, which is composed of silty mud with scattered gravel. The mud is up to 8 m thick and contains several zones of shallow gas. In the shallower water towards the head of the bay, the seabed appears more reflective on sidescan sonograms and displays point source reflections. This indicates the presence locally of a hard, gravelly bottom. Photographs of the seabed show angular to subangular gravel overlying a muddy substratum. On either side and at the head of the bay, the mud grades into gravelly, muddy sand that is exposed on intertidal flats.

Twenty-one grab samples were collected from the subtidal zone and 42 from beaches (including a raised beach at Hunts Cove). Twenty-three of the 63 samples were sent for assay. The procedure for determining gold levels in the Dog Bay–Gander Bay region differed from that used for most other areas in that a Kuryluk separator was used and head grades were derived using two methods (Edwardson et al., 1993a). Here we report values obtained using the second method, which may overestimate the gold in the total sample, particularly if, as elsewhere in the region, much of the gold resides in the mud fraction. As shown in Figure 61, gold levels exceed 50 ppb at two of nine sites in Dog Bay and at five of fourteen sites in Gander Bay. The values were generally below 200 ppb, but sample 031, from 3 m water depth off Victoria Cove, was assayed at 1449 ppb. Values obtained for the same samples using the first method did not exceed 7 ppb, except for the Victoria Cove sample 031 (45 ppb).

This region does not have significant potential to host marine placer gold. The gold levels are not particularly high and the volumes of sand and gravel contained in the beaches and shoreface deposits are small. In addition, wave energy is low in these bays and sorting is therefore ineffective.

Hamilton Sound

Hamilton Sound (Fig. 62) is a shallow body of coastal water that, despite being somewhat protected by Fogo Island, is nevertheless exposed to waves from the Atlantic. A shallow (<18 m) region extends from Frederickton to Western Indian Island. Water depths increase eastward of the shallow area, reaching a maximum of 60 m at the entrance of the sound, and westward, attaining a maximum of 80 m just west of the Dog Bay Islands. Small islands and shoals are found throughout the sound. The coastline is mostly low and rocky, commonly with large boulders strewn across the intertidal zone, particularly east of Carmanville. The beaches are composed of gravel and are mostly small, but larger beaches occur in several places, notably at Ladle Cove.

Quaternary sediments are thin in Hamilton Sound (Jenner and Shaw, 1992; Fig. 63). Bedrock outcrops (unit 1) are common on the seabed, principally in the following areas: 1) a swath extending from the mainland to Western Indian Island; 2) off Fogo Island and the eastern mainland; 3) on a ridge extending east from Eastern Indian Island; and 4) in isolated locations in the west, e.g. around Steering Island, Gulnare Rocks, and Vesuvius Rock (Fig. 62).

Glacial diamicton (unit 2) is present throughout the sound, mostly in thicknesses up to several metres and filling bedrock depressions. However, at the mouth of Gander Bay and elsewhere, it forms 15 m high drumlins, such as those shown in Figure 64, whose crests are at 20 m water depth. One of the drumlins measured 200 m by 250 m by 10 m and its long axis was oriented 075°. This is consistent with the onshore indicators of ice flow from the west-southwest, mapped by St. Croix and Taylor (1991). These landforms may be offshore equivalents of onshore drumlins or drumlinoid features whose long axes range from 345° to 050° (Munro, 1993).

Deposits of glaciomarine mud (unit 3) up to 4 m thick occur in small basins in eastern Hamilton Sound and are separated from the overlying postglacial, silty sand by an unconformity. A gastropod *(Natica clausa)* in unit 3 sediments in vibracore 91026-042 (water depth 60 m) is dated at 11 620 ± 100 BP. Unit 5, postglacial gravel, sand, and muddy sand, is ubiquitous in Hamilton Sound and often occurs as bouldery veneers, sheets of mobile, rippled gravel several metres thick, and basin-fill deposits.

The bouldery gravel veneers are found around bedrock outcrops and overlying glacial diamicton. The gravel is subangular to subrounded, and the long axes of its clasts are typically less than 1 m, with no dominant shape. It is coarse and bouldery on top of seabed highs, but finer in depressions. Large-volume IKU grab samples show that the gravel also occurs as a thin (0.15 m) layer overlying sand. Figures 65a, b, and c illustrate the variability of sorting and grain size within the bouldery gravel. Figure 65a was taken at a depth of 70 m west of Dog Bay Islands, close to the site of grab sample 90035-001. It shows subangular pebbles and cobbles with a thin layer of finer sediment. Figure 65b was taken in 24 m of water due north of Eastern Indian Island, close to the site of grab sample 90035-047. It shows subrounded to rounded gravel clasts that are partly coated with the coralline alga *Lithothamnion* sp. and form a thin layer on top of sand. Many of the clasts appear to have been overturned, which is interpreted as evidence for intermittent seabed mobility. Figure 65c was taken in 41 m of water near Aspen Cove, near the site of grab sample 90035-059. It shows subangular to subrounded clasts that do not appear to have been overturned, which suggests less seabed mobility in this area.

Mobile gravel is found particularly in the western part of the sound, for example just southeast of Dog Bay Islands. Sample 90035-043 was collected off the south coast of Fogo Island at a water depth of 18 m, near gravel ripples with 2 m wavelengths. It consisted of a very poorly sorted mixture of sand and fine pebbles.

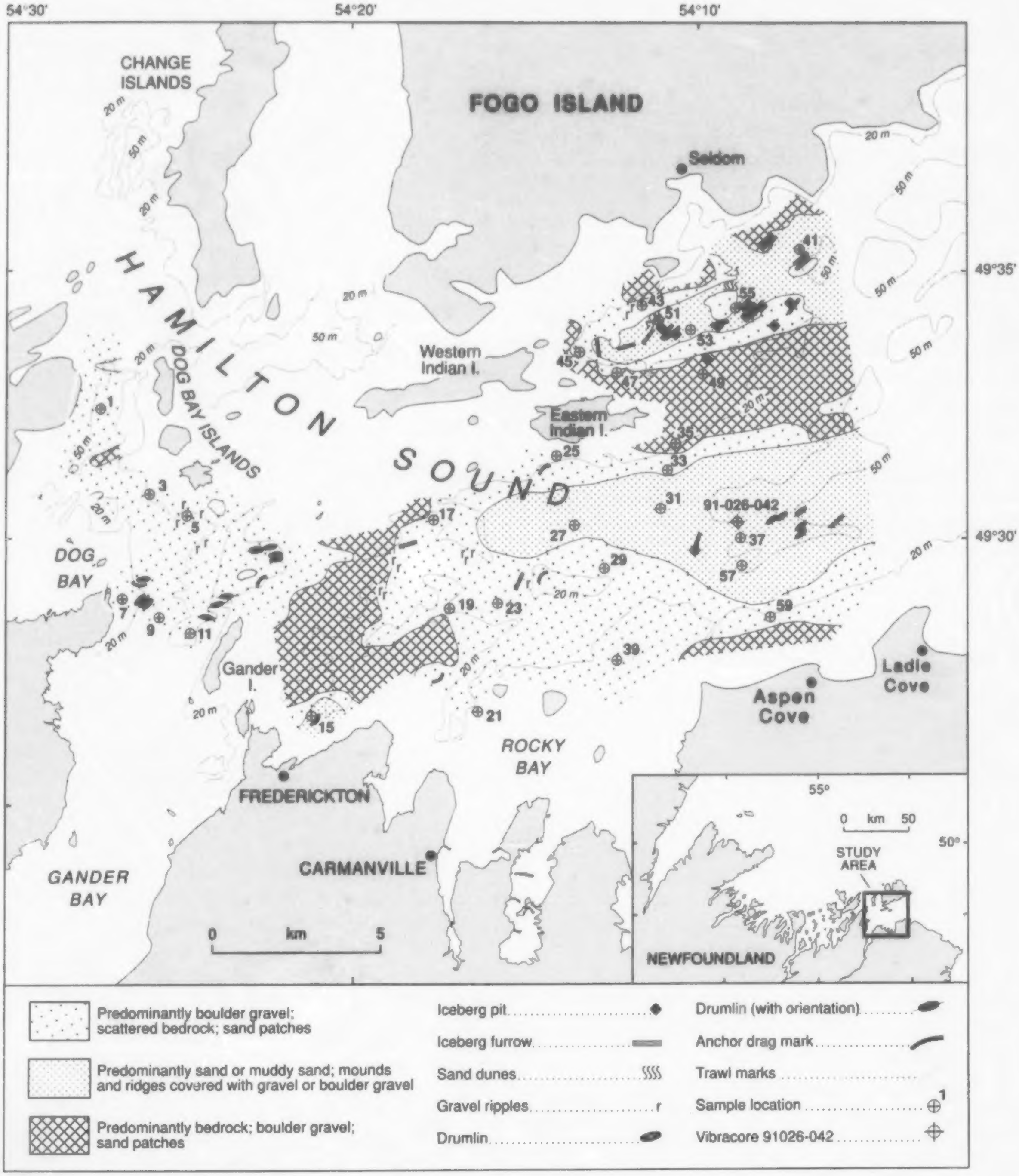


Figure 63. Map showing surficial sediments in Hamilton Sound.

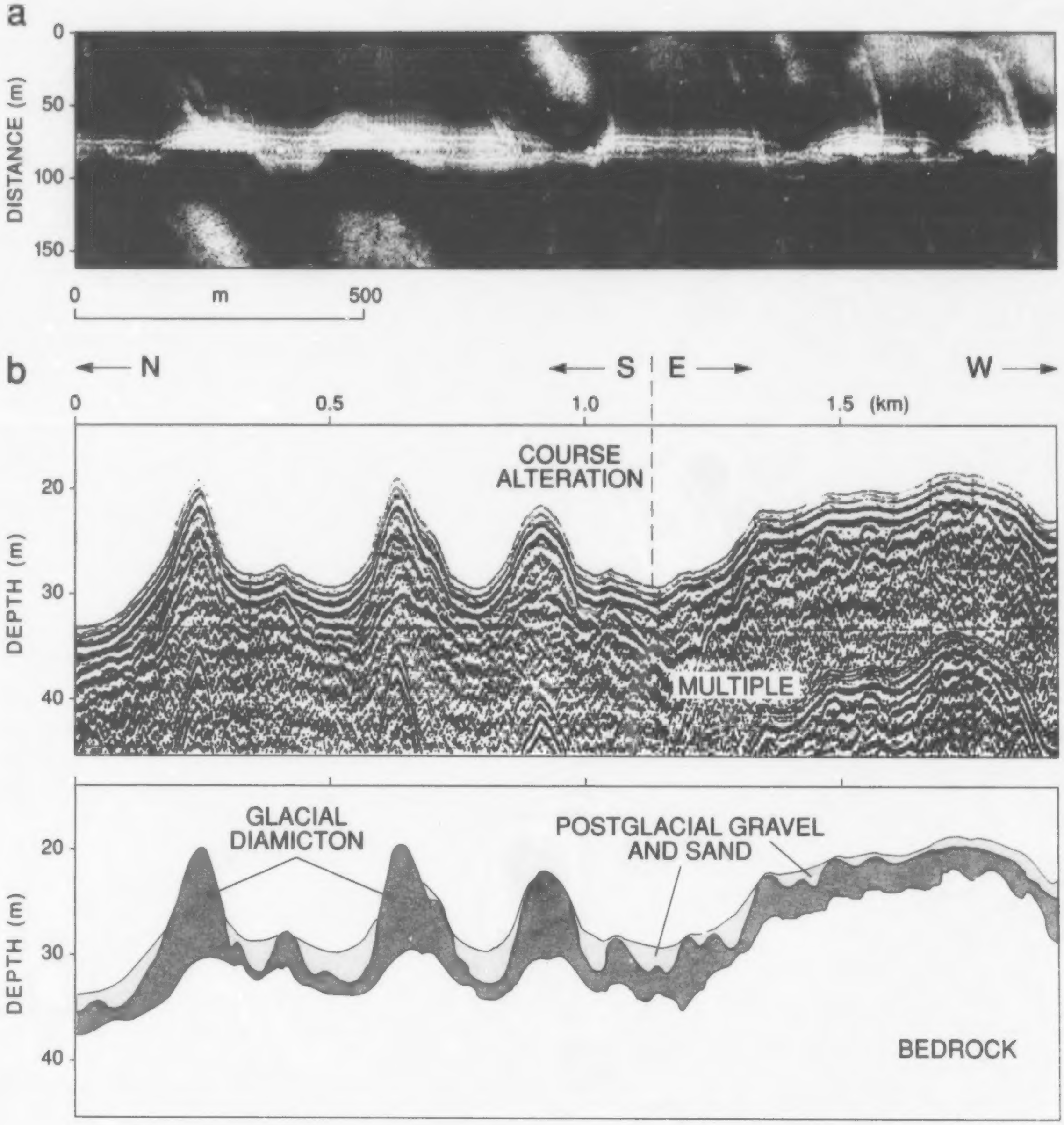


Figure 64. a) *Rectified sidescan sonar image (500 kHz) of drumlins northwest of Gander Island, western Hamilton Sound (see Figure 62 for location). **b)** Seistec high-resolution seismic reflection profile across drumlins (see Figure 62 for location).*

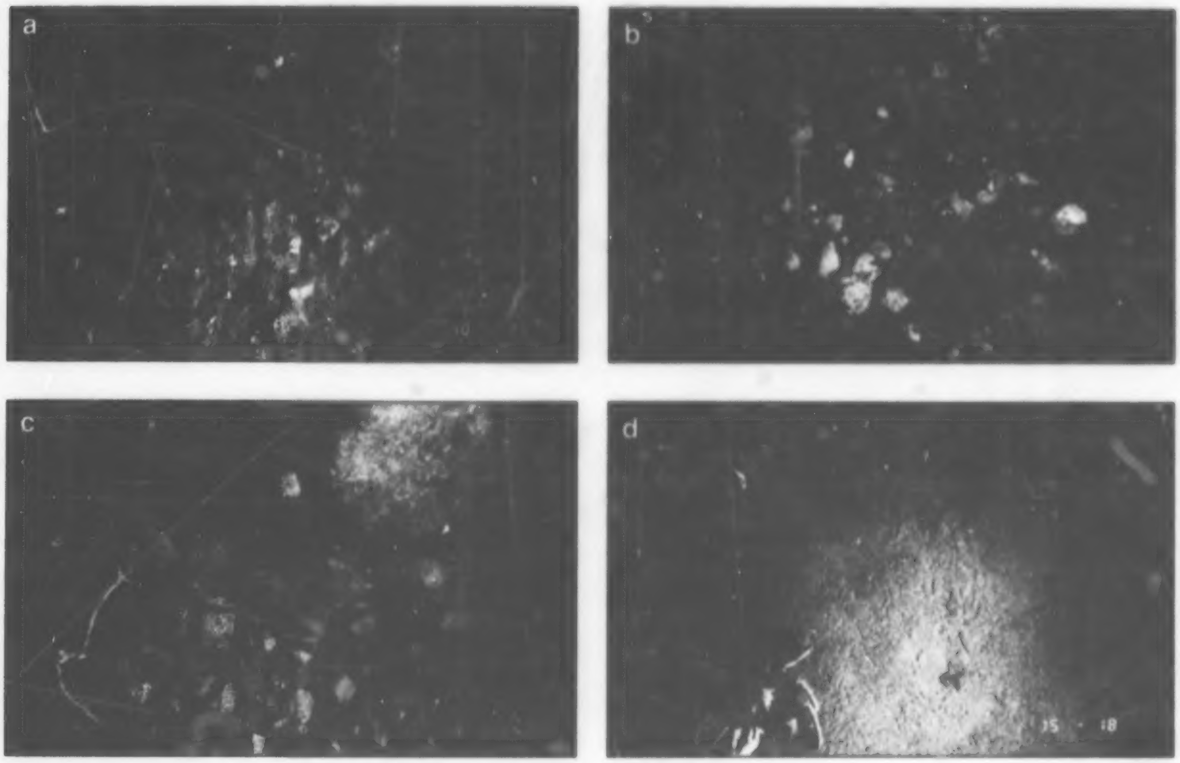


Figure 65. Bottom photographs from Hamilton Sound (see text for descriptions); a) GSC 1998-055M, b) GSC 1998-055N, c) GSC 1998-055O, d) GSC 1998-055P.

Medium to fine sand or muddy sand with moderate- to low-intensity, continuous, coherent, onlapping reflections are found in deeper areas, in particular the middle of the sound, south of Fogo Island, and offshore from Frederickton. On the periphery of the most extensive occurrences, the sand forms isolated or narrow, interconnecting bodies in depressions ponded between bedrock or glacial diamicton highs. The upper 0.90 m of core 91026-042 contained silty sand with shell fragments, shell hash, scattered pebbles, and concentrated bands of branching bryozoans. Samples from the middle of the bay (90035-027, 90035-031, 90035-037, and 90035-057) have varied grain-size distributions ranging from gravelly, muddy sand (sample 90035-027, water depth 41 m) to sandy mud (sample 90035-037, water depth 58 m). In general, grain size decreases with increasing water depth.

North of Eastern Indian Island, sand fills topographic depressions and forms isolated patches on a gravel substratum; its distribution is more patchy than in the central bay. Medium to large dunes (using the nomenclature of Ashley, 1990) occur in water depths of 36 m and have average wavelengths of 12 m and heights of less than 0.5 m. Their crests are oriented north-south. Sample 90035-051 (water depth 34 m) was collected close to the dunes and consisted of 2 per cent gravel, 74 per cent sand, and 24 per cent mud. The photograph of the seafloor taken near the site of grab sample 90035-041 (Fig. 65d), at a water depth of 50 m off the coast of Fogo Island, shows a fine-grained seabottom scribed with animal tracks. The principal seabed features in this area (and to a lesser extent in the larger sandy region) are furrows and pits formed as a result of iceberg grounding. They are best preserved on gravelly seabottoms within this zone. The pits are shallow (about 1 m), typically 10 m by 10 m, and circular to elliptical in planform. They are invariably filled with sand and the most recent ones have gravelly berms. Furrows are typically about 40 m long, straight to slightly curvilinear, with a mean width of 5 m (the narrowest observed was 3 m). A relatively wide furrow with triple berms was 18 m wide. Some furrows terminate in pits.

The extent of coarse sediment in Hamilton Sound and the evidence of mobility (gravel ripples, sand dunes) clearly demonstrate the relatively great impact of wave action on the seabed. This wave action could have led to the winnowing of gold-bearing glacial sediments, had they been present. Twenty of the 30 van Veen grab samples collected during cruise 90035 were analyzed for gold (Emory-Moore, 1991). Only one (sample 033, 52 ppb) contained over

50 ppb Au. It was collected several kilometres southeast of Eastern Indian Island at a water depth of 28 m. It also contained particulate gold (3.4 ppb) in the sand fraction. All five grains showed evidence of chemical and mechanical alteration and are believed to have been transported over 500 m. Six IKU samples and two cores were collected during cruise 91026. Gold particles were found in samples 91026-036 and 91026-037, neither of which had gold concentrations above 50 ppb in the mud fraction.

Several of the factors for gold placer potential identified by S.M. Solomon and M. Emory-Moore (unpub. rept., 1989) exist in Hamilton Sound. Firstly, wave energy is sufficient to rework glacigenic sediments and also frequently to remobilize the sands and gravels produced by reworking. Secondly, the sea level remained within a narrow range (0 to -17 m) throughout the Holocene. Unfortunately, the low gold levels found in samples confirm the absence of the third, and most essential, factor: the presence of source sediments.

Inner shelf from Cape Freels to Fogo Island

The southern part of this region (Fig. 66) is underlain by Devonian granites and the northern part, off Fogo Island, by Silurian–Devonian sedimentary rocks (Fader et al., 1989). A narrow strip of Ordovician sedimentary rocks extends southwestard into Hamilton Sound. The seabed is smooth in the deep (>300 m) areas well offshore that are underlain by Cretaceous–Tertiary sedimentary rocks. In contrast, it is more rugged in shallow areas closer to the coast. An isolated, 73 m high bedrock pinnacle is found midway between the Wadham Islands and Funk Island. A cluster of three pinnacles (73, 55, and 55 m high) is located one-third of the distance between Fogo Island and Funk Island. A Klein sidescan sonar fish was lost when it hit the first pinnacle in this group, which reached to within 47 m of the sea surface.

As Shaw and Forbes (1990a) showed, the northeast-oriented coast in this region, the so-called 'Straight Shore', is remarkable for the number of sandy beaches and dunes that are found there compared with elsewhere in Newfoundland, and also for the presence of Holocene coastal landforms that are several thousand years old. The large dune-ridge foreland at Man Point is overlain by a 3 m thick blanket of freshwater peat that started to form at 3.2 ka. The barrier at Deadman's Bay was formerly transgressive, but by 1.8 ka it had stabilized in its present position and moribund flood deltas and overwash channels were becoming covered by marshes and woodlands. At Cape Freels, the southeastern limit of the study area, extensive coastal dunes had stabilized and were becoming covered by peat-forming vegetation by 1.6 ka. These data led Shaw and Forbes (1990a) to conclude that the sea level rose by only 0.7 m after 3 ka and that the area had experienced a long period of sea-level stability. The postglacial relative sea level in this region fell from a marine limit between +43 m (Grant, 1980) and +67 m (Catto, 1993) to below the present sea level by 10 ka (Shaw and Forbes, 1990a), and reached a lowstand at -17 m before 8.6 ka (Shaw and Edwardson, 1994).

Several zones of surficial sediments are recognized off the coast. In an inner zone that extends to an average depth of 75 m, relief averages a few metres. Bedrock outcrops veneered with boulders are present on about 5 per cent of the seabed and are surrounded by gravel and sand deposits whose thicknesses average several metres and locally up to 9 m. Gravel ripples are very extensive (Fig. 67) and several large sheets were mapped in 1991, including one in a water depth of 55 m that extended 7 km. Gravel ripples in the area imaged using sidescan sonar had an average wavelength of 2.3 m (18 measurements) and the orientation of their troughs and crests varied between 108° and 152°, with a tendency to swing clockwise (i.e. more parallel to the shore) towards the coast. Ripples were observed at depths ranging from 29 to 73 m. Sand sheets generally overlie gravel. Sandy dunes are seen at the edges of sand sheets on sidescan sonograms. Dune wavelength at one location averaged 8 m.

Numerous icebergs, many of which seemed to be grounded, were found within the inner zone during the sidescan sonar survey on 5 July 1991. Several very fresh, multiple-keel grounding pits are seen on the sonograms. The furrow and pit shown in Figure 68 are at a water depth of 73 m on a fine gravel bottom. Such grounding records are unlikely to be preserved because of the high degree of mobility of the sand and gravel deposits due to wave and current action. The potential for preservation of these records is much higher in deeper water (*see* below).

In the outer coastal zone below a water depth of 75 m, relief is more rugged and ranges up to 70 m. Bedrock outcrops are more common; they cover about 20 per cent of the seabed and are smoother and less bouldery than in the inner zone. The surrounding sediments are highly furrowed and pitted by icebergs. It is tempting to deduce that this change in bedrock character may have been caused by a postglacial, relative sea-level lowstand (i.e. the shallower area was truncated in the intertidal zone by wave action), but this is not the case, for two reasons: 1) in parts of the inner zone, bedrock relief reaches 10 m, but is masked by sand and gravel; 2) more importantly, in the northeast corner of the survey block, between the Wadham Islands and Funk Island in water depths of 125 to 150 m, bedrock outcrops covering 50 to 80 per cent of the seabed have a relief similar to that observed in the shallow zone. Thus, the variations in relief are more probably caused by some variation in bedrock properties. As noted above, the postglacial lowstand of relative sea level in this region was about -17 m.

A majority of IKU samples from cruise 92042 (samples 05, 07, 08, 09, 10, 46, 48, 51, and 52), collected off the east coast of Fogo Island in water depths ranging from 51 m to

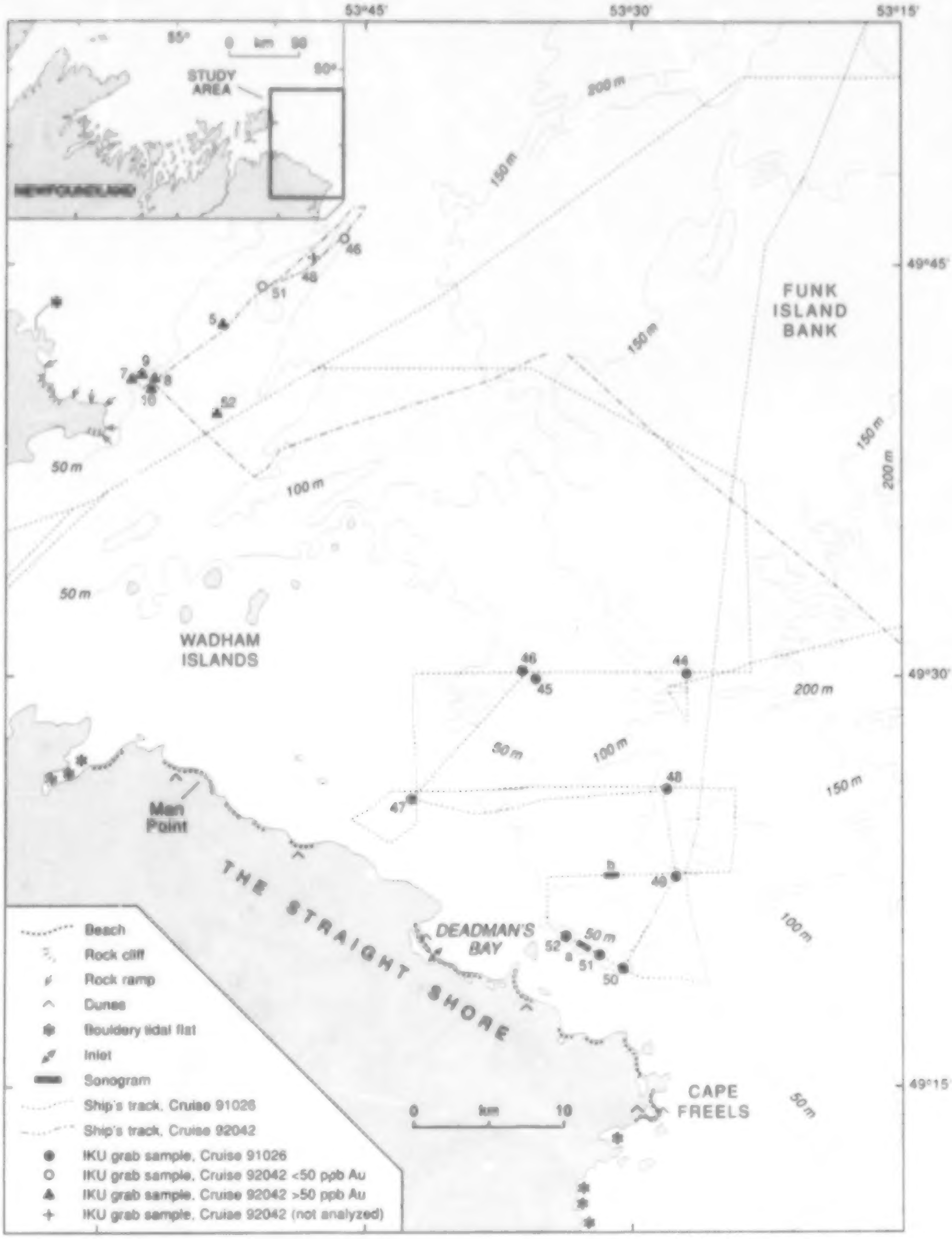


Figure 66. *Map of the inner shelf between Fogo Island and Cape Freels, including The Straight Shore region.*

Figure 68. *Klein 595 sidescan-sonar image (cruise 91026) showing a fresh iceberg scour on a fine-gravel bottom in a water depth of 73 m, approximately 10 km northeast of Deadman's Bay, The Straight Shore. Day/time 186/17:00–17:05 ('b' in Fig. 66).*

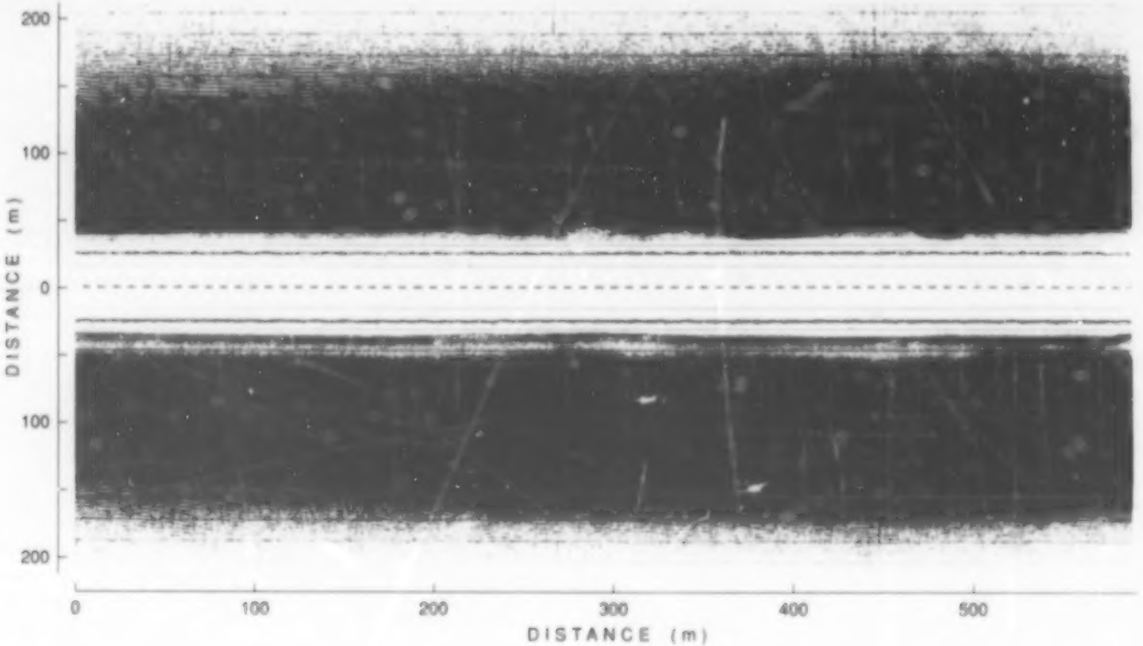
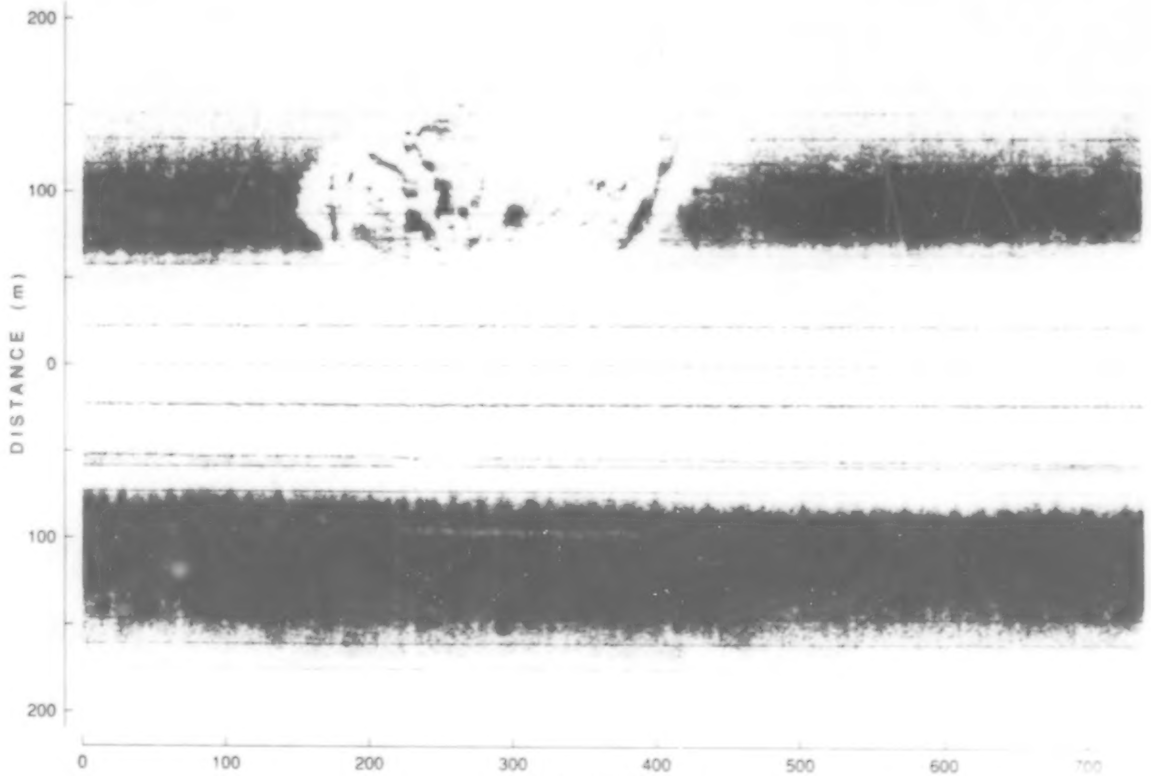


Figure 67. Klein 595 sidescan sonar image of gravel ripples in a water depth of 50 m off The Straight Shore. Cruise 91026, day/time 186/15:38–15:43 ('a' in Fig. 66).



119 m, mostly from the inner zone, consisted of well sorted, medium sand with shell hash. Four had surface layers of pebble-cobble gravel, one clast deep. Subsamples (except from sample 48) were sent for gold assay using a Kuryluk separator. Head grades were derived using two methods (Edwardson et al., 1993a). Here we report the values obtained using the second method, which may overestimate the gold in the total sample, particularly if, as elsewhere in the region, much of the gold resides in the mud fraction. Samples 46 and 51 had less than 50 ppb Au, whereas the remaining samples had between 68 and 540 ppb Au. Samples 5 and 8 each contained a single, visible gold particle measuring 225 µm and 190 µm, respectively. We do not attach much importance to these results, mainly because the gold levels determined using the first Kuryluk method are all less than 5 ppb. For example, sample 7 had the highest gold level using the second method (540 ppb), but a level of only 0.6 ppb using the first method.

Nine IKU samples from cruise 91026 (44 to 52, even numbers) were collected in water depths ranging from 43 to 113 m off The Straight Shore. Most were collected in the inner zone and, not unexpectedly, are coarse grained and contain less than 0.5 per cent mud (Emory-Moore and Davis, 1992). Samples from gravel ripples comprised sandy, fine gravel, with 60 to 80 per cent gravel; the gravel was described as pea-sized in sample 46. Samples from sandy areas (light toned on sonograms) ranged from medium to fine-medium sand. The sand generally contained pebbles, shell hash, and sand dollars (*Echinarachnius parma*), although sample 45 had less than 1 per cent gravel. Concentrations of gold in eight samples assayed were generally below detection limits. In their discussion of the geochemistry of grab samples from this region, Emory-Moore and Davis (1992) noted the presence of a unique element suite comprising hafnium, neodymium, samarium, and thorium, which they believed was related to the presence of the large granitic intrusion. They also noted that this area is at least 20 km from any known gold source.

Although this is a region of high wave energy and relative sea level has occupied a narrow vertical range for the past 10 000 years, low levels of gold in assayed samples and the absence of known gold sources lead us to conclude that the potential for marine placer gold is very low.

REGIONAL GEOCHEMISTRY AND GOLD OCCURRENCE

Gold in seabed samples

Twenty-nine samples from cruise 90013 were analyzed for gold; six contained over 50 ppb Au in a heavy-mineral concentrate (Appendix 1). Grain-size determinations were not completed, but on the basis of visual examinations, sediments ranged from sandy gravel to silty, sandy clay. Five of the six samples containing gold were taken from Baie Verte in water depths ranging from 25 to 242 m. The sixth gold-rich sample was taken from Notre Dame Bay at a water depth of 288 m. Other samples analyzed from Green Bay, Halls Bay, and Notre Dame Bay did not contain gold concentrations over 50 ppb.

Ninety-eight seabed grab samples were collected during cruise 90035. Fourteen of the 86 samples analyzed contained concentrations of gold greater than 50 ppb in the mud fraction; eight of these also contained particulate gold in the sand fraction, identified during panning (Appendix 1). Eleven of the 14 samples were collected from Baie Verte, in shallow coves less than 52 m deep. The other three samples containing gold were found off La Scie in 80 m of water, in the Sunday Cove Island area in 39 m of water, and in Hamilton Sound in 25 m of water.

Eighty-six grab samples were collected during cruises 91026 (39 samples) and 91031 (47 samples). Of the 78 samples analyzed, 19 contained over 50 ppb Au in the mud fraction (Appendix 1). Two of these also contained over 50 ppb Au in the sand fraction and eight contained visible gold grains in panned concentrates. An additional ten samples, with gold concentrations under 50 ppb, contained from 1 to 30 gold grains in panned samples. With the exception of one sample collected at water level, 17 of the 18 samples containing visible gold grains were taken at a water depth between 20 and 108 m. Samples with over 50 ppb Au that did not contain visible grains were collected at between 0 and 79 m water depth.

Fifty-nine of 132 samples from cruises 92301 and 92042 were assayed. Gold grains were identified from the sand fraction of six samples collected in water depths of 0–92 m (Appendix 1). Using the more conservative of two methods (Edwardson et al., 1993a), no gold values over 50 ppb were identified from these samples. Two of the samples, from Deer Cove and Victoria Cove, contained over 35 ppb Au in the mud fraction.

Figure 69 shows the distribution of gold values over 50 ppb and the water depth of seabed samples. These data suggest that gold is concentrated at present-day sea level on exposed, wave-reworked beaches in Hamilton Sound and to a lesser extent at sites in Green Bay and Ming's Bight. However, the distribution may also reflect a relative predominance of shoreline samples in Hamilton Sound, Green Bay, and Ming's Bight compared with the number collected elsewhere along the northeast coast. The gold concentration in samples collected at 40–50 m water depth reflects wave-reworked environments at Tilt Cove, Deer Cove (Baie Verte), and east of Fogo Island. There is a pronounced, secondary concentration of gold in the mud fraction of three samples taken from 77–80 m water depth in Tilt Cove (91026-011, 91026-013, and 91026-019) and two samples from the same depth off La Scie (90035-136 and 91026-027). Fresh grains were also identified in the sand fraction of the two samples collected 2 km off La Scie at a water depth of 77–80 m and, according to Emory-Moore (1991), they may reflect an extension of the onshore gold-bearing host rock to within 200 m from the sample sites. Additional gold grains from these two samples have abraded and corroded textures, which suggest that they may have been transported over 500 m from their source (Emory-Moore, 1991). Gold grains were identified in two samples taken offshore of Tilt Cove.

Gold-grain morphology

Gold-grain characteristics were determined from scanning electron microscope photographs of grains identified in samples from cruises 91031 and 91026 and are reported in Emory-Moore (1991). By comparison, microprobe photographs of gold grains observed in samples from cruises 92301 and 92042 provided only limited details on gold-grain surfaces. Gold-grain characteristics were not identified from the samples analyzed from cruise 90013 and therefore are not included in the gold-grain totals presented below. Two distinct populations of gold grains were identified from scanning electron microscope and microprobe photographs. The first population contains grains with fresh, irregular features, only minor folding of grain edges, minimal etching and little or no silver. These grains are interpreted to have travelled less then 500 m from their site of origin (Emory-Moore, 1991). Grains from the second population are more rounded or equidimensional and exhibit micro- and macrofolding and extensive surface matting, striations, and some percussion marks, all indicative of mechanical alteration. Extensive corrosive etching and pitting is also present on some grains. Grains from the second population are interpreted to have travelled over 500 m from their site of liberation (Emory-Moore, 1991).

The two populations are most easily differentiated in the samples from Deer Cove. Several grains from each of a large number of samples were examined. Highly abraded and extensively etched and pitted gold grains dominated the suite. A small number of fresh grains showed low levels of chemical and mechanical alteration (Emory-Moore and Davis, 1992). The sample from nearby Green Cove contained two gold grains and the two samples from Marble Cove contained only one gold grain each. These four grains exhibited moderate levels of mechanical alteration in the form of matting, folding of grain edges, and striations, as well as chemical abrasion as evidenced by extensive grain etching and pitting (Emory-Moore, 1991).

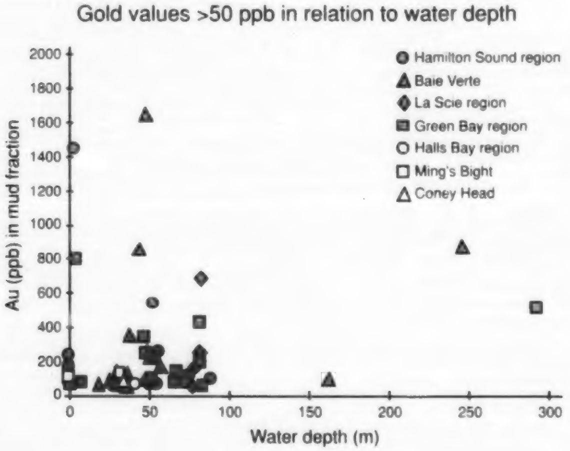


Figure 69. *Plot of gold concentration versus depth.*

Gold concentrations in the mud fraction in the samples from Ming's Bight ranged from 7 to 44 ppb. Only one gold grain was recovered from the sand fraction in one sample (91031-006) and it exhibited moderate to high levels of abrasion and chemical etching. Seven grains, identified from the mud fraction on an intertidal bar at the head of Ming's Bight (91031-001), represented two populations, the first with fresh chemical and mechanical characteristics and the second with a moderate to high degree of abrasion and chemical etching (Emory-Moore and Davis, 1992). Particulate gold was recovered from seven of eight samples collected offshore from La Scie during surveys conducted in 1990 and 1991. Six of these samples contained particulate gold in the mud fraction; one sample contained particulate gold in the sand fraction (Emory-Moore, 1991; Emory-Moore and Davis, 1992). Three of the samples (90035-136, 91026-026, and 91026-027) were characterized by a bimodal grain population dominated by gold grains exhibiting both mechanical abrasion and chemical etching. A limited number of fresh grains probably travelled less than 200 m from their place of origin. Grains in the rest of the samples showed a high degree of mechanical abrasion and chemical etching, suggesting a longer travel distance from the place of origin.

Particulate gold was recovered from two samples from the Tilt Cove area and one sample from Betts Cove. The grains from Tilt Cove were moderately to highly abraded and pitted and showed a moderate degree of chemical etching. Two of the three grains from the sample at Betts Cove were well worn and highly etched. The third grain was moderately abraded with little evidence of chemical etching (Emory-Moore and Davis, 1992). Gold concentrations northwest of New World Island, within Hamilton Sound and offshore of Cape Freels, were low in both the mud and sand fractions. Coarse particulate gold was recovered from three samples (90035-033, 91026-036, and 91026-037) collected in Hamilton Sound east of Eastern Indian Island. The grains in two of these samples exhibited signs of mechanical and chemical alteration. Grains from the third sample appear to have travelled a shorter distance. One gold grain was also identified in the sand fraction in each of two samples collected off New World Island. These grains were heavily abraded and etched and suggest long travel distances. A single gold grain found in Wild Bight (92042-042) displays both fresh surfaces and etched grain edges.

Two grains found in separate samples from due east of Fogo Island (92042-005 and 92042-008) are characterized by a moderate to high degree of mechanical and chemical abrasion.

Two particulate gold grains identified from samples in Nickey's Nose Cove and Upwards Cove, in Green Bay, seem to be heavily abraded and chemically etched. Fresh grains were not observed.

Two gold grains were recovered in a sample from Victoria Cove, in Gander Bay. One has a fresher, more irregular surface than the other, but both seem to have undergone some degree of chemical etching.

These data show that the two populations of grain morphologies — fresh and abraded — were represented in all areas where gold grains were identified, with the exception of the samples from Green Bay where no fresh grains (population 1) were observed. In addition, those samples containing several gold grains were dominated by mechanically and chemically altered grains of population 2, which are interpreted by Emory-Moore (1991) to have travelled over 500 m from their site of liberation.

Regional geochemistry and gold distribution

The northeastern Newfoundland Shelf was identified as a possible target for placer gold by Emory-Moore and Solomon (1989), on the basis of the compilation and integration of regional geological and geochemical data. The northeast coast meets two conditions considered to be critical for the occurrence of primary and secondary autochthonous beach and nearshore placer deposits: 1) proximity to source and 2) a moderate- to high-energy seabed environment necessary for placer concentration. Primary autochthonous deposits are derived through high-energy marine erosion of auriferous bedrock, whereas secondary autochthonous deposits form by marine reworking of auriferous glacigenic sediment, which preferentially concentrates particulate gold at the base of a gravel lag (Emory-Moore, 1991).

Results from this study show a significant variation, on a per sample basis, in sediment geochemistry between a split of the whole sample and a split of the mud fraction. Concentrations of most elements analyzed including gold, and except for chromium, rubidium, scandium, and sodium, were highest in the mud fraction of the sample and many elements from the mud fraction showed significant regional variation (Emory-Moore and Davis, 1992). The geochemistry of the mud fraction was ultimately used for provenance evaluations because it was also least likely to be affected by physical sorting processes (Emory-Moore, 1991).

The regional geochemistry described in the following section is based directly on analyses, observations, and patterns identified by Emory-Moore (1991) and Emory-Moore and Davis (1992).

Regional geochemical patterns observed in seabed samples seem to reflect local bedrock source terrains. An enrichment of calcium, barium, bromine, neodymium, and zinc in the seabed samples taken from the area surrounding Coney Head reflects the presence of granitoid intrusions exposed at the coast (Emory-Moore and Davis, 1992). Farther east, distinct differences in the sediment geochemistry of samples from inner and outer Baie Verte correspond to changes in the bedrock geology (Emory-Moore and Davis, 1992). The high calcium content of sediments in northwestern Baie Verte reflects a local exposure of carbonate rocks immediately west of the bay (Emory-Moore, 1991). Elevated concentrations of chromiun and nickel within Ming's Bight may be indicative of mafic and ultramafic rocks exposed along the western shore at the head of the bay (Emory-Moore and Davis, 1992). High cobalt and iron concentrations within Baie Verte, La Scie, and the Little Bay area may reflect local sulphide mineralization within coastal ophiolitic and gabbroic terrains (Emory-Moore, 1991). Similarly, sulphide mineralization within the coastal rock suites of the Tilt Cove area may be the source of high iron, cobalt, and zinc (Emory-Moore and Davis, 1992).

The geochemistry of the surficial shelf sediments farther east differs markedly from that of the remainder of the study area. The sediments are rich in hafnium, neodymium, samarium, and thorium, with the highest concentrations of these elements occurring in deep waters off the Musgrave Harbour–Cape Freels coast. This element suite may reflect the underlying granitic intrusion at the coast. Bromine concentrations are elevated off the Gander River mouth and northwest of New World Island and both of these areas are underlain by sedimentary rock (Emory-Moore and Davis, 1992).

Correlations between gold and other elements are not consistent throughout the study area. In the fourteen samples from cruise 90035 that contained anomalous gold concentrations in the mud fraction, Emory-Moore (1991) found gold to be highly correlated with chromium, tin, and tungsten in Baie Verte, but did not identify correlations between gold and other elements within the Halls Bay area. There is a negative correlation between gold content and cobalt and chromium and a positive correlation between gold and rubidium in the sediments of Hamilton Sound (Emory-Moore, 1991).

Anomalous primary autochthonous gold concentrations in the study area are found primarily near terrestrial zones of epigenetic mineralization in a moderate- to high-energy depositional environment (Emory-Moore, 1991). In addition to the above requirements, secondary autochthonous gold placers form as a result of reworking of gold-bearing, glacigenic sediment. Gold was found in sediments off Coney Head, White Bay, within 1.3 km of a known epigenetic vein deposit in a moderate- to high-energy environment, whereas the samples taken off Sops Arm and Jackson's Arm were collected more than 7 km from known sources and were barren. In Baie Verte, the highest concentrations of gold were found in a moderate-energy environment in Deer Cove, within 1 km from a known vein source of mineralization. Similarly, two gold-bearing samples off the north coast of New World Island were collected in a high-energy setting, within 1 km of a known source. The richest samples off Tilt Cove were collected 1.5, 3.0, and 6.5 km from known onshore epigenetic and massive sulphide mineralization. Barren samples collected in Hamilton Sound were 13 km away from the main zone of epigenetic mineralization. However, two samples from east of Eastern Indian Island that contained low gold concentrations were collected 5 km from a source of gold mineralization on the island. Barren samples collected offshore from the Musgrave Harbour to Cape Freels region are over 20 km from any known gold source. Conversely, ten samples taken in Halls Bay near an onshore gold source were barren. Here, the gold onshore is associated with massive sulphide mineralization, is generally fine grained, and may be easily dispersed, making it unsuitable for forming placers (Emory-Moore, 1991).

Data from this study indicate that Deer Cove, in Baie Verte, is the most favourable site for primary and secondary placer gold concentration. However, Emory-Moore and Davis (1992) note that samples from the upper 10 cm of the seabed at Deer Cove yield an estimated average whole-rock grade of only 5 ppb, which is below mining grades. They suggest that maximum concentrations of particulate gold would occur 30 to 60 cm below the seabed, but that this would likely form a low-volume deposit that would only sustain a small-scale operation.

CONCEPTUAL MODELS OF COASTAL AND INNER-SHELF ENVIRONMENTS

Autochthonous gold placer deposits are the principal focus of the present study. They are either primary (derived from reworking of bedrock) or secondary (formed by marine reworking of glacigenic sediments on the beach or inner shelf). With the exception of Deer Cove, no area with high potential for placers of either type has been found. Nevertheless, several generalized, qualitative models have been developed that explain the variation in character of modern marine, intertidal, and supratidal environments within the study area. These simple models take into account the styles of sedimentation during the period of glacial influence (i.e. to the beginning of the Holocene), subsequent modification of glacial sediments by marine processes and changing sea levels, and modern sedimentary processes. To some extent, they explain the distribution of gold at the coast and offshore, although the proximity to source is the ultimate determinant.

Three conceptual models are described. The first two (Fig. 70, 71) apply to non-fiord environments and are very similar. Whereas the first model (Fig. 70) applies to areas where the inner shelf is relatively deep and the wave-dominated zone is narrow, the second (Fig. 71) applies to areas where the inner shelf is relatively shallow and the wave-dominated zone is correspondingly wide. The third model (Fig. 72) applies to the marine environments in the numerous, long fiords that reach deep into the island.

Conceptual model of non-fiord environments

Modern marine and coastal environments in the study area can be zoned according to depth, which is the principal control on those processes that presently shape the seafloor: waves, currents, and impacting icebergs. In two highly generalized models, we describe five environmental zones that extend from deep water into the supratidal zone. Of the five zones, the relatively shallow wave- and current-dominated zone is of greatest importance for marine placers. The zones, illustrated in Figures 70 and 71, are described below (in order of decreasing water depth).

Basin zone

In the deep basins on the inner shelf, sedimentation has probably been continuous since deglaciation, so that relatively thick deposits of postglacial mud (unit 4) overlie stratified, glaciomarine sediment (unit 3). The basin zone lies below 370 m in White Bay and below 300 m in the Notre Dame Basin. Small amounts of ice-rafted gravel may occur on the muddy seafloor. No samples were collected in this zone because it does not have potential to host marine placers.

Basin transition zone

This zone lies above the basin zone. At its lower limit it appears as a zone of reduced deposition rates, so that acoustic, internal reflections are closer together than in the basin zone. In shallower water, however, the internal reflections are truncated at the seabed. In places, the postglacial sediments have been eroded completely, so that the underlying glaciomarine unit is exposed at the seabed. This is a modern unconformity, although in parts of White Bay (*see* Fig. 16), onlapping sedimentation subsequently buried the unconformity (the extrapolation of dated reflections from core 90013-035 dates the deepest parts of the unconformity in that area at 6-4 ka). Nondeposition and erosion in this zone may be due to a change in hydrodynamic regime after the early postglacial period, leading to more vigorous bottom currents.

Grab samples from this environment comprise muddy gravel, which shows that the winnowing of early postglacial sediments has led to the formation of a surface layer enriched in gravel; some gravel may have been added by ice rafting. In principle there is potential for enhanced levels of gold on the surface of the unconformity, but the low concentrations of gold in the winnowed source sediments, as evidenced by very low concentrations of gold in grab samples, and the relatively deep water substantially reduce the potential for marine gold placers.

Iceberg-impacted zone

In water shallower than 200 m, the effects of iceberg impacts are observed on the seabed as furrows and pits. In some instances, iceberg impact occurs far into the bays, for example in the Sunday Cove Island area, and into the shallow waters of the wave- and current-dominated zone, where wave action soon erases the evidence of iceberg scour. The iceberg-impacted zone is defined as the region in which the results of iceberg impact are preserved. Furrows predominate in deeper areas and pits are concentrated at the inner boundary of the zone. Iceberg impact can produce iceberg turbates, particularly at the shallower end of the depth range. The turbated sediments offshore from La Scie are a good example.

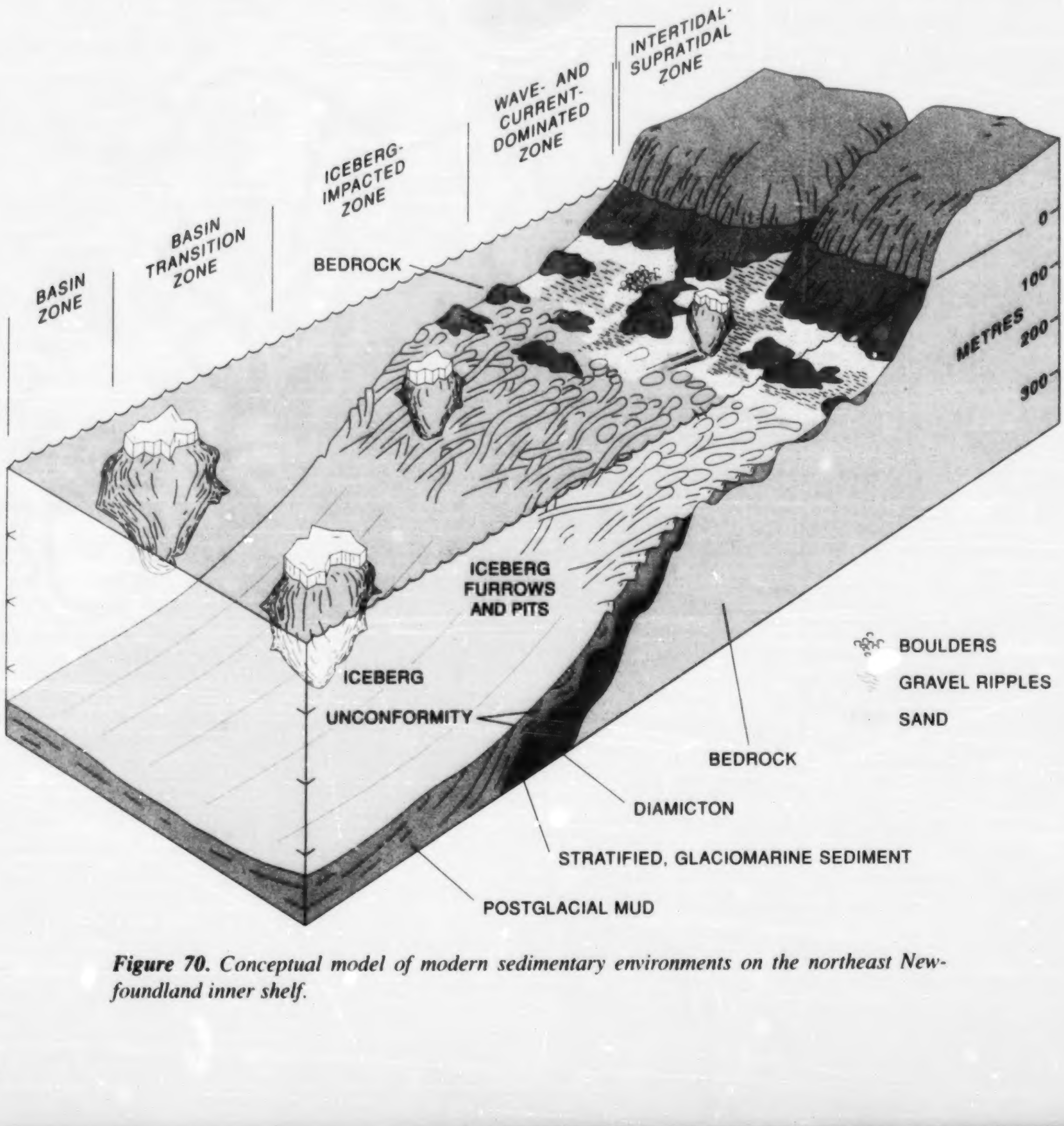


Figure 70. *Conceptual model of modern sedimentary environments on the northeast Newfoundland inner shelf.*

Where sediments are disturbed by icebergs, subsequent winnowing by currents theoretically enhances the potential for concentration of heavy mineral and fine gold particles at the seabed. However, the initial concentration of gold in the glaciomarine muds that are commonly disturbed by icebergs is very low and the enhancement is probably extremely slight. This zone is also deep, making it unsuitable for economic exploitation. Therefore, marine placer potential is low.

Wave- and current-dominated zone

This zone extends from a water depth of about 60 m to the coast. It is several kilometres wide off La Scie and 20 km wide off The Straight Shore. Sediments on the seabed are mobilized by wave action at a recurrence interval that is depth dependent (waves with a period of 12 s have a significant effect on the seabed above depths of 55 m and those with a period of 10 s, above 38 m). Asymmetrical tidal currents and wind-driven currents may impose a net transport direction. As noted above, icebergs can impact the seabed in this zone, especially in exposed, outer-coast settings, but the resulting pits and furrows are probably soon obliterated by wave action. Areas of mobile, clastic sediments have bedforms such as gravel ripples, sand dunes, and sand ribbons. Elsewhere, poorly sorted pebble-cobble-boulder gravels form intermittently mobile armoured lags over glacial diamicton or on top of pockets of finer sediment.

This is the principal zone for the formation of marine placers. The potential source materials are glacial diamicton and other ice-contact deposits, glaciomarine mud, and (less commonly) bedrock. The potential for reworking of these

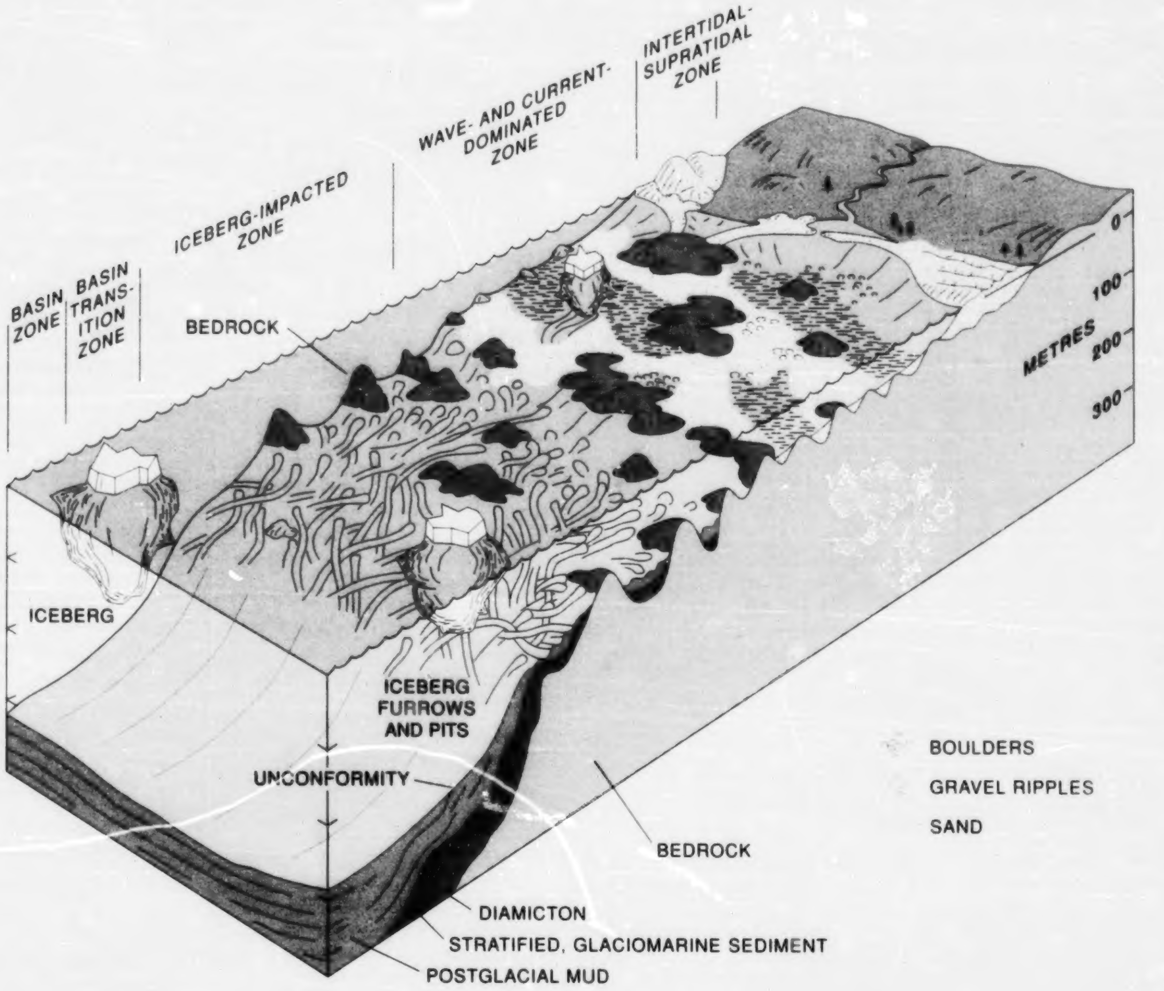


Figure 71. *Variant of the model shown in Figure 70, applicable to areas in which the inner shelf is shallow (e.g. off The Straight Shore).*

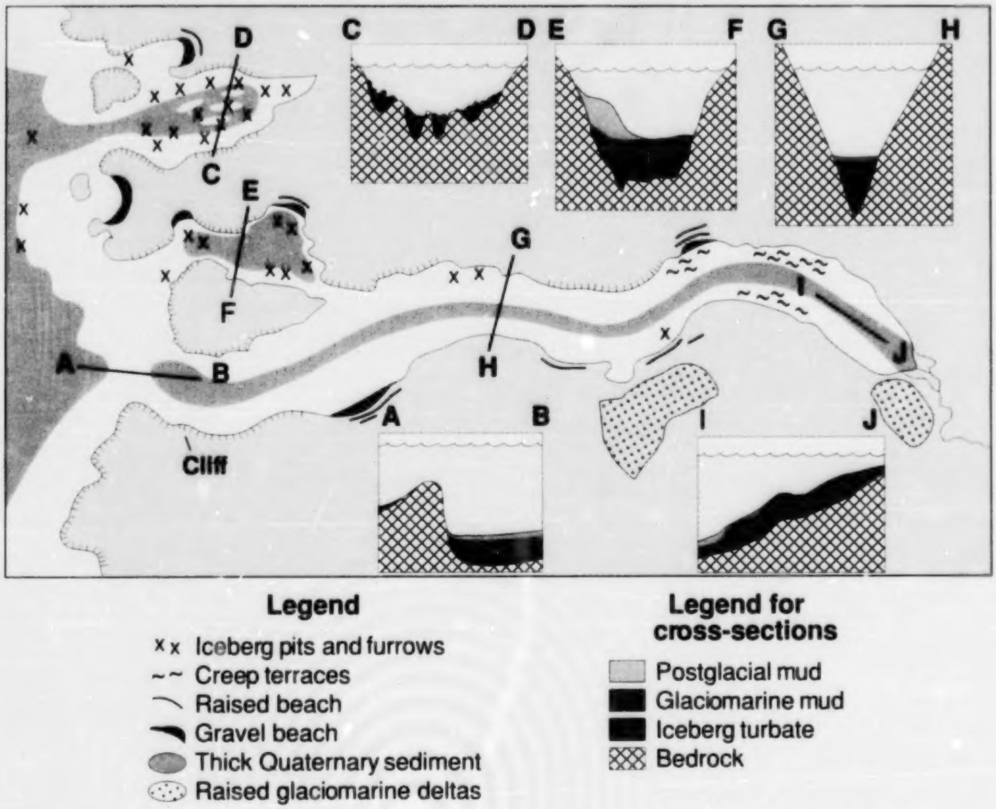


Figure 72. *Conceptual model of inner-shelf environments in fiords on the northeast Newfoundland inner shelf.*

source materials is greatest in the shallowest areas. As a rule, sufficient energy to significantly rework glacial diamicton is found only in the intertidal zone; in deeper water, reworking by waves results in an immobile, armoured lag of boulders and cobbles that arrests the winnowing process. In the east, where sea level was lower in the early Holocene, reworking of glacial diamicton could have occurred in a coastal fringe that extends down to 20 m below present sea level; in the west, there has been no reworking below present sea level.

Although the high wave energy and changes in sea level are favourable for placer development, especially in the shallow, exposed, northeast coast (The Straight Shore), the limited occurrence of glacigenic sediments in the coastal zone and the absence of gold in these sediments means that the likelihood of large placers having formed is low. Nevertheless, gold has been found at Deer Cove and in lesser amounts off La Scie, Tilt Cove, and in Dog Bay.

Intertidal-supratidal zone

This zone is only a few tens of metres wide on the steep bedrock shores with scattered pocket gravel beaches that predominate in the study area. The input of new sediment from coastal erosion and from rivers is negligible. However, the zone is relatively wide in the eastern part of the study area — The Straight Shore — where the shallow gradient of the inner shelf, high exposure to waves, and the occurrence of Quaternary sediments have resulted in the formation of a wide variety of sandy, coastal landforms: beaches, barriers, tombolos, a prograded dune-ridge foreland, and coastal dunes. In this area, there is slow, long-term adjustment to rising sea level, so that, for example, the largest sediment deposit, the Man Point dune foreland, is undergoing erosion and sediment is moving northwest towards Hamilton Sound.

Although the high wave energy is favourable for placer development, limited occurrences of glacigenic sediments in the coastal zone and the absence of gold in these sediments mean that the likelihood of large placers having formed is low. No samples were assayed from The Straight

Shore, where intertidal and supratidal sediments are abundant, but low gold levels in samples from the adjacent inner shelf (the wave- and current-dominated zone) indicate that gold levels would probably also be low at the coast.

Conceptual model of fiord environments

The existence of numerous fiords complicates the two conceptual models discussed above to the extent that an alternative model is necessary (Fig. 72). The complications include the existence of strong gradients of wave-energy levels from exposed, outer-fiord coasts to sheltered, inner-fiord coasts. Also, in some areas, the steep sidewalls greatly reduce the lateral extent of the four shallowest zones, although in other areas the seabed shelves more gently and the iceberg-impacted zone, for example, can predominate over large areas. The embayments encompassed by this model include inner White Bay, Green Bay, Baie Verte, Little Bay, Halls Bay (including the Sunday Cove Island area), Badger Bay, New Bay, and Bay of Exploits.

Outer-fiord environments

At fiord mouths, basins that are hundreds of metres deep are separated from the adjacent ocean by relatively shallow (about 100 m) bedrock sills (Fig. 72, section A-B). The sills have not been exposed in the surf zone because of limited postglacial sea-level lowering, so they are unlikely to have marine placers. The deep, muddy basin floors are also not of interest in this respect.

Shallow areas such as the Sunday Cove Island region, outer Baie Verte, Ming's Bight, and Little Bay are heavily impacted by icebergs, resulting in the formation of iceberg turbates (Fig. 72, section C-D). The turbated sediments are typically glaciomarine muds, augmented by ice-rafted gravel. Although winnowing probably occurs, it is unlikely to produce marine placers. In some areas, postglacial mud occurs in banked deposits (Fig. 72, section E-F) produced by strong bottom currents. The glaciomarine deposits exposed on the seafloor date back to 11 ka and earlier and lie below a thin lag of fine, pebbly gravel. Although currents have prevented postglacial deposition, the glaciomarine muds have rarely been significantly eroded, so enrichment of heavy-mineral populations by winnowing is limited.

Pocket beaches composed of pebble-cobble-boulder mixtures occur throughout this outer zone. The crenulate nature of the coast (that reduces wave activity in many areas) and the general lack of sediment in the outer-fiord environment mean that only small amounts of glacial sediment have been reworked in these beaches. The seabed immediately offshore is equivalent to the wave- and current-dominated zone of the previous model (*see* above). It is in such a setting that relatively high amounts of gold were discovered in Deer Cove, Baie Verte.

Middle-fiord environments

Between the outer coast and the innermost parts of fiords, the coasts are rocky, with scattered gravel beaches. The fiord sidewalls are steep and have a veneer of sediment, with the thickest deposits, mostly glaciomarine mud, in the deep, central part of the channel (Fig. 72, section G-H). With moderate to low wave energy, very little reworking, and no gold sources, this region has very low placer potential overall, although enhanced levels of gold were found in such a setting in inner Baie Verte.

Inner-fiord environments

In inner-fiord environments, wave energy is low, so that beaches have low crest heights and typically consist of either fine gravel or sand. The relative sea-level history has resulted in the formation of raised beaches and raised, glaciomarine deltas, notably in Halls Bay and Green Bay. Deltas composed of coarse-grained material occur at the head of almost every fiord and have formed as a result of reworking of glacial sediments; the delta within Sops Arm is a good example. Offshore, the water is relatively shallow and sediments consist mainly of glaciomarine, gravelly, sandy mud with a patchy veneer of postglacial mud or sandy mud (Fig. 72, section I-J). Creep terraces are common on steep fiord sidewalls. The low wave energy results in poor potential for marine placer development.

FUTURE WORK

It is useful to note those aspects of the marine geology of this region that require more research. They include the rates of iceberg impact, the question of relict versus modern ice-scour features, the hydrodynamic processes in fiords that form banks of postglacial mud adjacent to areas of nondeposition, the origin of the widespread unconformity in early postglacial sediments (e.g. in eastern White Bay), and the limit of Late Wisconsinan ice on the Northeast Newfoundland Shelf.

Lastly, since the project was completed, multibeam sonar has become an important marine geological tool, providing shaded relief and backscatter imagery of the seafloor. Multibeam bathymetric systems could provide high-resolution images of the great variety of seafloor features found on the Northeast Newfoundland Shelf, including the range of iceberg-impact features that lend particular distinction to the region.

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APPENDIX 1

Sample inventory and gold values

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
90013-036	139 (HMC)	sandy mud	head of Baie Verte	49°56.31′N 56°10.96′W	30	van Veen
90013-037	< 5 (HMC)	gravelly, sandy mud	head of Baie Verte	49°56.63′N 56°09.95′W	37	van Veen
90013-038	< 5 (HMC)	muddy, sandy gravel	head of Baie Verte	49°57.16′N 56°09.17′W	49	van Veen
90013-039	< 5 (HMC)	sandy mud	Baie Verte	49°57.48′N 56°09.20′W	59	van Veen
90013-040	97 (HMC)	sandy mud	Baie Verte	49°57.90′N 56°09.28′W	47	van Veen
90013-041	10 (HMC)	stiff mud	Baie Verte	49°58.13′N 56°08.97′W	77	van Veen
90013-042	1650 (HMC)	sandy gravel	Green Cove	49°49.61′N 56°07.06′W	48	IKU
90013-043	91 (HMC)	muddy gravel	off Lower Green Cove	50°00.48′N 56°06.52′W	162	van Veen
90013-044	< 5 (HMC)	stiff, silty clay	Baie Verte	50°01.00′N 56°06.60′W	191	van Veen
90013-045	870 (HMC)	mud	Baie Verte	50°01.55′N 56°05.19′W	247	van Veen
90013-046	not analyzed	soft, silty clay	Baie Verte	50°01.42′N 56°04.91′W	316	van Veen
90013-047	no sample	no sample	Baie Verte	50°01.72′N 56°03.52′W	56	IKU
90013-048	13 (HMC)	sandy mud	Baie Verte	50°02.26′N 56°03.31′W	233	van Veen
90013-049	no sample	no sample	Baie Verte	50°02.52′N 56°01.68′W	60	IKU
90013-050	510 (HMC)	silty, sandy clay	off Betts Cove	49°45.93′N 55°38.34′W	293	van Veen
90013-052	< 5 (HMC)	sandy mud	off Betts Cove	49°49.42′N 55°36.05′W	233	van Veen
90013-053	27 (HMC)	fine-medium sand	off Tilt Cove	49°51.87′N 55°35.25′W	103	van Veen
90013-055	< 5 (HMC)	stiff mud	off Tilt Cove	49°50.48′N 55°27.08′W	258	van Veen
90013-056	< 5 (HMC)	stiff, sandy mud	off Tilt Cove	49°51.25′N 55°26.87′W	262	van Veen
90013-057	not analyzed	sandy gravel	off Shoe Cove	49°53.15′N 55°27.59′W	152	van Veen
90013-058	< 5 (HMC)	muddy, coarse sand	off Shoe Cove	49°54.13′N 55°27.12′W	102	van Veen
90013-059	35 (HMC)	fine sand	off Tilt Cove	49°51.77′N 55°33.71′W	155	van Veen
90013-060	26 (HMC)	muddy, fine sand	off Tilt Cove	49°51.02′N 55°30.45′W	232	van Veen
90013-061	< 5 (HMC)	soft mud	off Betts Cove	49°47.32′N 55°42.76′W	280	van Veen
90013-062	< 5 (HMC)	gritty mud	off Betts Cove	49°48.05′N 55°44.77′W	234	van Veen
90013-065	< 5 (HMC)	sandy, gravelly mud	Halls Bay	49°45.38′N 55°39.63′W	278	van Veen
90013-066	< 5 (HMC)	sandy, gravelly mud	Halls Bay	49°45.37′N 55°39.76′W	282	van Veen
90013-067	< 5 (HMC)	sandy mud	off Nippers Harbour	49°45.88′N 55°49.98′W	297	van Veen
90013-068	< 5 (HMC)	very gritty mud	off Confusion Bay	50°01.09′N 55°46.02′W	198	van Veen
90013-069	< 5 (HMC)	sandy, gravelly mud	off Confusion Bay	50°03.39′N 55°48.72′W	210	van Veen
90013-070	< 5 (HMC)	very sandy mud	off Confusion Bay	50°05.79′N 55°50.60′W	216	van Veen
90035-001	not analyzed	gravel and sand	W Dog Bay Islands	49°32.07′N 54°27.03′W	83	van Veen
90035-003	not analyzed	gravel and sand	SW Dog Bay Islands	49°30.60′N 54°25.72′W	29	van Veen
90035-005	not analyzed	gravel and sand	S Dog Bay Islands	49°30.26′N 54°24.57′W	28	van Veen
90035-007	0	mud	off Dog Bay Point	49°28.77′N 54°26.20′W	19	van Veen
90035-009	10	mud	mouth of Gander Bay	49°28.47′N 54°25.16′W	29	van Veen
90035-011	11	mud	mouth of Gander Bay	49°28.21′N 54°24.32′W	25	van Veen
90035-013	0	mud	mouth of Gander Bay	49°28.54′N 54°23.82′W	33	van Veen
90035-015	0	mud	off Frederickton Harbour	49°26.77′N 54°20.80′W	22	van Veen
90035-017	5	mud	Hamilton Sound	49°30.38′N 54°17.71′W	24	van Veen
90035-019	not analyzed	gravel	northwest Noggin Island	49°28.82′N 54°17.12′W	30	van Veen
90035-021	0	mud	Hamilton Sound	49°26.98′N 54°16.37′W	21	van Veen
90035-023	not analyzed	gravel; trace sand	N Noggin Island	49°28.94′N 54°15.86′W	31	van Veen
90035-025	0	mud	S Eastern Indian I.	49°31.59′N 54°14.42′W	18	van Veen
90035-027	0	mud	Hamilton Sound	49°30.37′N 54°13.88′W	41	van Veen
90035-029	not analyzed	gravel	Hamilton Sound	49°29.63′N 54°13.02′W	31	van Veen
90035-031	not analyzed	sand and silt	Hamilton Sound	49°30.72′N 54°11.55′W	49	van Veen
90035-033	52	mud	Hamilton Sound	49°31.44′N 54°11.38′W	28	van Veen
90035-033	3.4	sand				
90035-035	not analyzed	boulder	SE Eastern Indian I.	49°31.90′N 54°11.08′W	15	van Veen
90035-037	6	mud	Hamilton Sound	49°30.27′N 54°09.26′W	58	van Veen
90035-039	not analyzed	gravel	Hamilton Sound	49°28.00′N 54°12.56′W	27	van Veen
90035-041	12	mud	Hamilton Sound	49°35.47′N 54°07.87′W	50	van Veen
90035-043	10	mud	Hamilton Sound	49°34.36′N 54°12.22′W	18	van Veen
90035-045	6	mud	N Eastern Indian I.	49°33.48′N 54°13.88′W	23	van Veen
90035-047	10	mud	N Eastern Indian I.	49°33.14′N 54°12.85′W	25	van Veen
90035-049	not analyzed	gravel	S Fogo Island	49°33.18′N 54°10.42′W	21	van Veen
90035-051	0	mud	Hamilton Sound	49°34.11′N 54°11.76′W	34	van Veen
90035-053	0	mud	Hamilton Sound	49°33.98′N 54°10.86′W	39	van Veen
90035-055	16	mud	Hamilton Sound	49°34.36′N 54°09.60′W	39	van Veen

Appendix 1. (cont.)

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
90035-057	12	mud	Hamilton Sound	49°29.77'N 54°09.19'W	58	van Veen
90035-059	9	mud	Hamilton Sound	49°28.88'N 54°05.47'W	41	van Veen
90035-061	27	mud	off Green Cove	49°59.54'N 56°07.60'W	58	van Veen
90035-063	15	mud	off Green Cove	49°59.42'N 56°07.65'W	32	van Veen
90035-065	10	mud	off Schooner Cove	49°59.26'N 56°08.85'W	67	van Veen
90035-067	0	mud	Baie Verte	49°59.06'N 56°08.38'W	41	van Veen
90035-069	60	mud	off Upper Duck I. Cove	49°59.08'N 56°08.82'W	18	van Veen
90035-071	0	mud	off Fire Cove	49°58.76'N 56°08.80'W	62	van Veen
90035-073	0	mud	Baie Verte	49°58.16'N 56°09.58'W	41	van Veen
90035-075	24	mud	Pine Cove	49°58.10'N 56°08.52'W	45	van Veen
90035-077	11	mud	Baie Verte	49°57.79'N 56°09.25'W	61	van Veen
90035-079	58	mud	off Lower Sisters Cove	49°57.76'N 56°09.62'W	32	van Veen
90035-081	15	mud	Baie Verte	49°57.36'N 56°08.86'W	28	van Veen
90035-083	9	mud	Baie Verte	49°57.16'N 56°09.82'W	35	van Veen
90035-085	20	mud	Baie Verte	49°56.70'N 56°09.65'W	23	van Veen
90035-087	20	mud	Baie Verte	49°56.53'N 56°10.58'W	30	van Veen
90035-089	11	mud	Baie Verte	49°56.37'N 56°10.58'W	34	van Veen
90035-091	13	mud	Baie Verte	49°56.11'N 56°11.43'W	16	van Veen
90035-093	9	mud	Coachman's Harbour	50°03.47'N 56°05.82'W	32	van Veen
90035-095	7	mud	Coachman's Harbour	50°03.45'N 56°06.60'W	21	van Veen
90035-097	6	mud	Coachman's Harbour	50°03.78'N 56°05.87'W	30	van Veen
90035-099	7	mud	Coachman's Harbour	50°03.86'N 56°05.40'W	60	van Veen
90035-101	not analyzed	gravel	Baie Verte	50°02.37'N 56°02.01'W	50	van Veen
90035-103	347	mud	Deer Cove	50°01.53'N 56°03.69'W	38	van Veen
90035-105	859	mud	Deer Cove	50°01.55'N 56°03.19'W	44	van Veen
90035-105	7.6	sand				
90035-107	250	mud	Deer Cove	50°01.42'N 56°03.28'W	49	van Veen
90035-107	1.6	sand				
90035-109	224	mud	Deer Cove	50°01.26'N 56°03.60'W	54	van Veen
90035-109	1.9	sand				
90035-111	226	mud	Deer Cove	50°01.20'N 56°03.50'W	50	van Veen
90035-111	1.6	sand				
90035-113	9	mud	Baie Verte	50°01.91'N 56°06.88'W	41	van Veen
90035-115	8	mud	Lower Green Cove	50°00.31'N 56°06.10'W	75	van Veen
90035-117	43	mud	Green Cove	50°00.02'N 56°06.84'W	63	van Veen
90035-119	21	mud	Marble Cove	50°00.62'N 56°07.75'W	36	van Veen
90035-121	81	mud	Marble Cove	50°00.63'N 56°07.91'W	31	van Veen
90035-121	0.5	sand				
90035-123	0	mud	Marble Cove	50°00.54'N 56°08.18'W	21	van Veen
90035-125	86	mud	Marble Cove	50°00.48'N 56°08.02'W	25	van Veen
90035-127	36	mud	Green Cove	49°59.84'N 56°06.96'W	48	van Veen
90035-129	56	mud	Green Cove	54°59.42'N 56°07.04'W	36	van Veen
90035-131	127	mud	Green Cove	49°59.52'N 56°06.88'W	36	van Veen
90035-131	1.2	sand				
90035-136	684	mud	off La Scie	49°59.92'N 55°34.17'W	83	van Veen
90035-136	3.5	sand				
90035-138	0	mud	off La Scie	50°00.13'N 55°36.35'W	113	van Veen
90035-140	not analyzed	sandy gravel	off La Scie	49°58.33'N 55°36.88'W	55	van Veen
90035-142	7	mud	Little Bay	49°36.22'N 55°53.28'W	60	van Veen
90035-144	0	mud	Little Bay	49°36.27'N 55°53.50'W	59	van Veen
90035-146	0	mud	Little Bay	49°36.58'N 55°55.86'W	57	van Veen
90035-148	0	mud	Little Bay	49°36.57'N 55°55.52'W	66	van Veen
90035-150	7	mud	Little Bay	49°36.75'N 55°55.52'W	52	van Veen
90035-152	0	mud	Sunday Cove	49°29.59'N 55°46.34'W	37	van Veen
90035-154	17	mud	Sunday Cove	49°29.76'N 55°45.57'W	52	van Veen
90035-156	0	mud	Sunday Cove	49°30.03'N 55°45.47'W	57	van Veen
90035-158	0	mud	Sunday Cove	49°30.57'N 55°45.39'W	70	van Veen
90035-160	0	mud	Sunday Cove	49°31.44'N 55°47.66'W	77	van Veen
90035-162	0	mud	Sunday Cove	49°31.38'N 55°47.75'W	78	van Veen
90035-164	11	mud	Sunday Cove	49°31.25'N 55°47.30'W	59	van Veen
90035-166	0	mud	Sunday Cove	49°32.00'N 55°46.89'W	85	van Veen

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
90035-168	0	mud	Sunday Cove	49°31.86′N 55°46.23′W	155	van Veen
90035-170	0	mud	Sunday Cove	49°32.35′N 55°46.65′W	53	van Veen
90035-172	0	mud	Sunday Cove	49°33.57′N 55°44.96′W	43	van Veen
90035-174	0	mud	Sunday Cove	49°33.84′N 55°46.22′W	109	van Veen
90035-176	18	mud	Sunday Cove	49°34.78′N 55°45.08′W	83	van Veen
90035-178	64	mud	Sunday Cove	49°35.42′N 55°44.60′W	42	van Veen
90035-186	0	mud	head of Halls Bay	49°25.62′N 56°07.08′W	34	van Veen
90035-188	0	mud	head of Halls Bay	49°25.95′N 56°06.82′W	57	van Veen
90035-190	0	mud	head of Halls Bay	49°26.33′N 56°06.18′W	75	van Veen
90035-192	9	mud	mouth of South Brook R.	49°25.96′N 56°05.60′W	63	van Veen
90035-194	5	mud	head of Halls Bay	49°26.90′N 56°05.28′W	199	van Veen
90035-196	5	mud	off White Point	49°27.27′N 56°03.69′W	61	van Veen
90035-198	0	mud	off Springdale	49°29.90′N 56°02.50′W	124	van Veen
90035-200	0	mud	off Springdale	49°29.93′N 56°02.84′W	81	van Veen
90035-202	0	mud	off Springdale	49°29.95′N 56°03.22′W	67	van Veen
90035-204	0	mud	off Springdale	49°29.88′N 56°03.38′W	69	van Veen
91031-001	102	mud	head of Ming's Bight	49°58.60′N 56°02.74′W	0	hand grab
91031-001	< 5	sand				
91031-002	< 5	mud	head of Ming's Bight	49°59.00′N 56°01.99′W	~43	van Veen
91031-002	< 5	sand				
91031-003	8	mud	Ming's Bight	49°59.53′N 56°01.48′W	51	van Veen
91031-003	< 5	sand				
91031-004	7	mud	Ming's Bight	49°59.59′N 56°00.64′W	~54	van Veen
91031-004	< 5	sand				
91031-005	9	mud	head of Ming's Bight	49°59.14′N 56°01.72′W	65	van Veen
91031-005	< 5	sand				
91031-006	15	mud	Ming's Bight	49°59.98′N 56°00.51′W	80	van Veen
91031-006	< 5	sand				
91031-007	25	mud	Ming's Bight	50°00.30′N 56°00.13′W	38	van Veen
91031-007	< 5	sand				
91031-008	44	mud	Ming's Bight	50°00.92′N 56°00.53′W	49	van Veen
91031-008	32	sand				
91031-009	9	mud	mouth of Ming's Bight	50°01.32′N 55°59.73′W	113	van Veen
91031-009	< 5	sand				
91031-010	not analyzed	gravel and sand	mouth of Ming's Bight	50°01.89′N 56°00.48′W	41	van Veen
91031-011	121	mud	mouth of Ming's Bight	50°01.12′N 56°03.30′W	32	van Veen
91031-011	6	sand				
91031-012	95	mud	Deer Cove	50°01.42′N 56°03.20′W	50	van Veen
91031-012	< 5	sand				
91031-013	7	mud	head of White Bay	41°32.45′N 56°52.31′W	0	hand grab
91031-013	< 5	sand				
91031-014	85	mud	Coney Head	49°56.60′N 56°43.43′W	34	van Veen
91031-014	< 5	sand				
91031-016	< 5	mud	Coney Head	49°57.06′N 56°43.26′W	36	van Veen
91031-016	< 5	sand				
91031-018	not analyzed	gravel and sand	Coney Head	49°57.55′N 56°42.77′W	~33	van Veen
91031-020	< 5	mud	Coney Head	49°57.28′N 56°41.93′W	~53	van Veen
91031-020	< 5	sand				
91031-022	not analyzed	gravel and sand	Coney Head	49°57.79′N 56°43.78′W	38	van Veen
91031-024	10	mud	Coney Head	49°57.99′N 56°44.64′W	53	van Veen
91031-024	< 5	sand				
91031-026	19	mud	Great Coney Arm	49°58.08′N 56°45.42′W	123	van Veen
91031-026	< 5	sand				
91031-028	< 5	mud	Coney Head	49°58.12′N 56°44.37′W	56	van Veen
91031-028	< 5	sand				
91031-030	not analyzed	gravel and sand	Frenchman's Cove	49°53.36′N 56°44.27′W	36	van Veen
91031-032	not analyzed	gravel and sand	Jackson's Arm	49°51.64′N 56°46.38′W	27	van Veen
91031-034	21	mud	Jackson's Arm	49°51.51′N 56°45.11′W	90	van Veen
91031-034	7	sand				
91031-036	6	mud	mouth of Sops Arm	49°45.29′N 56°48.76′W	69	van Veen
91031-036	< 5	sand				

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
91031-038	< 5	mud	NE end of Sops Island	49°46.24′N 56°46.85′W	48	van Veen
91031-038	< 5	sand				
91031-040	< 5	mud	Hampden Bay	49°33.07′N 56°51.51′W	41	van Veen
91031-040	< 5	sand				
91031-042	< 5	mud	Hampden Bay	49°33.89′N 56°51.25′W	65	van Veen
91031-042	< 5	sand				
91031-044	not analyzed	gravel	Salt Water Cove	49°42.22′N 56°47.56′W	20	van Veen
91031-046	< 5	mud	Lower Head	49°43.57′N 56°47.25′W	54	van Veen
91031-046	< 5	sand				
91031-048	< 5	mud	Spear Point	49°44.40′N 56°48.25′W	50	van Veen
91031-048	< 5	sand				
91031-050	14	mud	quarry, Sops Arm	49°46.58′N 57°55.27′W	0	hand grab
91031-050	< 5	sand				
91031-051	8	mud	quarry, Sops Arm	49°46.51′N 57°55.30′W	0	hand grab
91031-051	< 5	sand				
91031-052	18	mud	mouth of Main River	49°46.09′N 57°55.92′W	0	hand grab
91031-052	< 5	sand				
91031-053	12	mud	W, Giles Cove	49°45.30′N 57°54.30′W	0	hand grab
91031-053	< 5	sand				
91031-054	< 5	mud	Moreton's Harbour	49°36.41′N 54°54.47′W	113	van Veen
91031-054	< 5	sand				
91031-056	13	mud	Moreton's Harbour	49°36.08′N 54°51.98′W	83	van Veen
91031-056	< 5	sand				
91031-058	< 5	mud	Moreton's Harbour	49°36.13′N 54°50.83′W	62	van Veen
91031-058	< 5	sand				
91031-060	15	mud	N, Wild Bight	49°36.74′N 54°49.82′W	58	van Veen
91031-060	< 5	sand				
91031-062	< 5	mud	N, Wild Bight	49°36.44′N 54°49.74′W	53	van Veen
91031-062	< 5	sand				
91031-064	< 5	mud	Wild Bight	49°36.22′N 54°49.72′W	58	van Veen
91031-064	< 5	sand				
91031-066	< 5	mud	Wild Bight	49°36.15′N 54°49.64′W	57	van Veen
91031-066	< 5	sand				
91031-068	< 5	mud	Webber Bight	49°36.11′N 54°49.06′W	46	van Veen
91031-068	< 5	sand				
91031-070	< 5	mud	Bear Gulch, New World I.	49°33.30′N 54°53.87′W	58	van Veen
91031-070	< 5	sand				
91031-072	9	mud	Whale Gulch, New World I.	49°33.65′N 54°53.86′W	43	van Veen
91031-072	< 5	sand				
91031-074	not analyzed	gravel	Sam Cove, New World I.	49°34.63′N 54°54.87′W	61	van Veen
91031-076	< 5	mud	NW of New World I.	49°35.85′N 54°55.19′W	52	van Veen
91031-076	< 5	sand				
91026-011S†	190	mud	Tilt Cove	49°59.29′N 55°36.15′W	82	IKU
91026-011S-2	251	mud				
91026-011S-3	240	mud				
91026-011S	27	sand				
91026-011S-2	28	sand				
91026-011S-3	25	sand				
91026-011B	420	mud	Tilt Cove	49°59.29′N 55°36.15′W	82	IKU
91026-011B-2	495	mud				
91026-011B-3	480	mud				
91026-011B	21	sand				
91026-011B-2	33	sand				
91026-011B-3	24	sand				
91026-012S	340	mud	Tilt Cove	49°52.56′N 55°37.28′W	47	IKU
91026-012S-2	404	mud				
91026-012S-3	417	mud				
91026-012S	93	sand				
91026-012S-2	100	sand				
91026-012S-3	112	sand				
91026-012M§	234	mud	Tilt Cove	49°52.56′N 55°37.28′W	47	IKU

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
91026-012M-2	230	mud				
91026-012M-3	234	mud				
91026-012M	83	sand				
91026-012M-2	117	sand				
91026-012M-3	105	sand				
91026-013	425	mud	Tilt Cove	49°52.09′N 55°37.21′W	82	IKU
91026-013-2	536	mud				
91026-013-3	500	mud				
91026-013	29	sand				
91026-013-2	40	sand				
91026-013-3	36	sand				
91026-014	25	mud	Betts Cove	49°48.40′N 55°46.27′W	71	IKU
91026-014	< 5	sand				
91026-015	not analyzed	boulders	Betts Cove	49°48.40′N 55°46.26′W	71	IKU
91026-016	28	mud	Betts Cove	49°48.41′N 55°46.27′W	71	IKU
91026-016	< 5	sand				
91026-017	not analyzed	sandy gravel	Tilt Cove	49°52.15′N 55°34.78′W	82	IKU
91026-018	not analyzed	pebbles, trace sand	Tilt Cove	49°52.08′N 55°34.88′W	84	IKU
91026-019	53	mud	Tilt Cove	49°52.10′N 55°34.87′W	84	IKU
91026-019	< 5	sand				
91026-020	246	mud	Tilt Cove	49°52.25′N 55°37.05′W	49	IKU
91026-020-2	367	mud				
91026-020	< 5	sand				
91026-021	95	mud	Tilt Cove	49°52.77′N 55°35.69′W	52	IKU
91026-021	< 5	sand				
91026-022	not analyzed	gravel	Tilt Cove	49°51.67′N 55°37.99′W	64	IKU
91026-023	145	mud	Tilt Cove	49°51.50′N 55°37.76′W	67	IKU
91026-023	< 5	sand				
91026-024S	81	mud	Tilt Cove	49°53.47′N 55°34.60′W	66	IKU
91031-024S	< 5	sand				
91026-024B	76	mud	Tilt Cove	49°53.47′N 55°34.60′W	66	IKU
91026-024B	< 5	sand				
91026-025S	75	mud	Tilt Cove	49°52.14′N 55°35.89′W	73	IKU
91026-025S	< 5	sand				
91026-025B	113	mud	Tilt Cove	49°52.14′N 55°35.89′W	73	IKU
91026-025B	< 5	sand				
91026-026	109	mud	La Scie	49°58.60′N 55°37.27′W	71	IKU
91026-026	< 5	sand				
91026-027	249	mud	La Scie	49°59.44′N 55°36.35′W	82	IKU
91026-027	< 5	sand				
91026-028	not analyzed	boulders	La Scie	49°59.53′N 55°36.11′W	71	IKU
91026-029	35	mud	La Scie	49°59.54′N 55°35.96′W	80	IKU
91026-029	< 5	sand				
91026-030	48	mud	La Scie	49°59.51′N 55°36.03′W	78	IKU
91026-030	< 5	sand				
91026-031	26	mud	La Scie	49°59.19′N 55°36.61′W	82	IKU
91026-031	< 5	sand				
91026-033	11	mud	La Scie	50°00.10′N 55°36.18′W	113	IKU
91026-033	< 5	sand				
91026-034	5	mud	La Scie	50°00.63′N 55°36.47′W	122	IKU
91026-034	< 5	sand				
91026-035	7	mud	Gull Island	49°54.29′N 55°22.42′W	233	IKU
91026-035	< 5	sand				
91026-036	33	mud	Hamilton Sound	49°31.45′N 54°11.53′W	25	IKU
91026-036	< 5	sand				
91026-037	< 5	mud	Hamilton Sound	49°31.32′N 54°11.51′W	31	IKU
91026-037	< 5	sand				
91026-038S	< 5	mud	Hamilton Sound	49°30.56′N 54°09.10′W	60	IKU
91026-038S	< 5	sand				
91026-038B	< 5	mud	Hamilton Sound	49°30.56′N 54°09.10′W	60	IKU
91026-038B	< 5	sand				
91026-039	< 5	mud	Hamilton Sound	49°31.48′N 54°07.64′W	45	IKU

Appendix 1. (cont.)

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
91026-039	< 5	sand				
91026-040	< 5	mud	Hamilton Sound	49°31.48′N 54°07.66′W	45	IKU
91026-040	< 5	sand				
91026-043	< 5	mud	Hamilton Sound	49°32.04′N 54°06.73′W	56	IKU
91026-043	5	sand				
91026-044	15	mud	SE Fogo Island	49°29.91′N 53°26.93′W	298	IKU
91026-044	< 5	sand				
91026-045	< 5	sand	Funk Island area	49°29.88′N 53°35.45′W	67	IKU
91026-046	< 5	mud	Funk Island area	49°29.96′N 53°35.59′W	67	IKU
91026-046	< 5	sand				
91026-047	11	mud	Funk Island area	49°25.40′N 53°42.34′W	43	IKU
91026-047	< 5	sand				
91026-048	10	mud	Penguin Islands	49°25.60′N 53°28.43′W	113	IKU
91026-048	< 5	sand				
91026-049	< 5	mud	near Deadman's Bay	49°22.50′N 53°27.68′W	95	IKU
91026-049	< 5	sand				
91026-050	< 5	mud	off Lumsden	49°19.10′N 53°30.70′W	56	IKU
91026-050	< 5	sand				
91026-051	< 5	mud	off Lumsden	49°19.65′N 53°32.14′W	54	IKU
91026-051	< 5	sand				
91026-052	< 5	mud	off Lumsden	49°20.33′N 53°33.90′W	54	IKU
91026-052	< 5	sand				
92301-001	not analyzed	pebbles and sand	Victoria Cove	49°20.88′N 54°29.44′W	0	trowel
92301-002	not analyzed	sand and pebbles	Victoria Cove	49°20.89′N 54°29.44′W	0	trowel
92301-003	not analyzed	pebbly sand	Victoria Cove	49°20.89′N 54°29.43′W	0	trowel
92301-004	not analyzed	sand and pebbles	Victoria Cove	49°20.89′N 54°29.42′W	0	trowel
92301-005	5.6*/100.9‡	pebbly sand	Victoria Cove	49°20.87′N 54°29.43′W	0	trowel
92301-006	not analyzed	sand and granules	Victoria Cove	49°20.87′N 54°29.43′W	0	trowel
92301-007	not analyzed	sand and pebbles	Victoria Cove	49°20.86′N 54°29.43′W	0	trowel
92301-008	not analyzed	sand and pebbles	Victoria Cove	49°20.73′N 54°29.36′W	0	trowel
92301-009	not analyzed	sand and pebbles	Victoria Cove	49°20.74′N 54°29.35′W	0	trowel
92301-010	not analyzed	sand and pebbles	Victoria Cove	49°20.92′N 54°29.25′W	3	Ponar
92301-011	not analyzed	sand and granules	Victoria Cove	49°20.93′N 54°29.15′W	4	van Veen
92301-012	2.2*/21.0‡	gravel and silt	Victoria Cove	49°21.06′N 54°29.20′W	3	van Veen
92301-013	not analyzed	sand and pebbles	Hunt's Cove	49°31.71′N 54°29.82′W	0	trowel
92301-014	not analyzed	sand and granules	Hunt's Cove	49°31.71′N 54°29.82′W	0	trowel
92301-015	1.0*/155.0‡	sand and pebbles	Hunts Cove	49°31.73′N 54°29.80′W	0	trowel
92301-016	not analyzed	sand and granules	Hunt's Cove	49°31.74′N 54°29.86′W	0	trowel
92301-017	not analyzed	sand and gravel	gravel pit, Hunt's Cove	49°31.85′N 54°30.03′W	0	trowel
92301-018	not analyzed	sand and pebbles	Dog Bay	49°31.00′N 54°29.97′W	0	trowel
92301-019	not analyzed	sand and granules	Dog Bay	49°31.07′N 54°29.99′W	0	trowel
92301-020	not analyzed	sand and granules	Dog Bay, west side	49°29.73′N 54°31.22′W	0	trowel
92301-021	not analyzed	sand and shell hash	Dog Bay, west side	49°29.73′N 54°31.22′W	0	trowel
92301-022	not analyzed	sand	Dog Bay, west side	49°29.73′N 54°31.22′W	0	trowel
92301-023	not analyzed	sand and granules	Dog Bay, west side	49°29.73′N 54°31.22′W	0	trowel
92301-024	not analyzed	sand and granules	Rodgers Cove	49°21.93′N 54°30.29′W	0	trowel
92301-025	not analyzed	sand and granules	Rodgers Cove	49°21.93′N 54°30.28′W	0	trowel
92301-026	5.8*/239.9‡	sand and granules	Rodgers Cove	49°21.97′N 54°30.23′W	0	trowel
92301-027	not analyzed	pebbly, muddy sand	Rodgers Cove	49°22.04′N 54°30.41′W	0	trowel
92301-028	6.8*/172.7‡	sand	Rodgers Cove	49°22.06′N 54°30.30′W	0	trowel
92301-029	not analyzed	sand and pebbles	Victoria Cove	49°20.97′N 54°29.26′W	2	van Veen
92301-030	not analyzed	sand and pebbles	Victoria Cove	49°21.00′N 54°29.14′W	4	van Veen
92301-031	44.9*/1449.4‡	sandy, gritty mud	Victoria Cove	49°20.97′N 54°29.00′W	3	van Veen
92301-032	not analyzed	sandy gravel and pebbles	Victoria Cove	49°20.95′N 54°29.07′W	3	van Veen
92301-033	1.1*/22.0‡	pebbly mud	Gander Bay	49°23.70′N 54°26.74′W	17	van Veen
92301-035	not analyzed	gravelly mud	Gander Bay	49°24.57′N 54°26.27′W	18	van Veen
92301-037	not analyzed	shelly sand and pebbles	Dog Bay	49°30.49′N 54°27.92′W	28	van Veen
92301-039	2.6*/15.8‡	muddy sand	Dog Bay	49°31.06′N 54°28.56′W	35	van Veen
92301-041	1.7*/7.0‡	sandy silt	Dog Bay	49°30.71′N 54°29.55′W	23	van Veen
92301-043	not analyzed	pebbly, muddy sand	Dog Bay	49°29.51′N 54°28.85′W	10	van Veen
92301-044	0.5*/8.0‡	muddy, pebbly sand	Dog Bay	49°29.49′N 54°28.83′W	14	van Veen

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
92301-046	not analyzed	silty mud	Dog Bay	49°28.68′N 54°30.74′W	21	van Veen
92301-048	1.1*/11.0‡	sandy silt	Dog Bay	49°27.97′N 54°31.83′W	10	van Veen
92301-050	not analyzed	muddy sand and pebbles	Dog Bay	49°27.56′N 54°32.26′W	7	van Veen
92301-052	not analyzed	mud and gravel	Gander Bay	49°27.39′N 54°27 57′W	14	van Veen
92301-053	not analyzed	mud	Gander Bay	49°25.65′N 54°24.63′W	35	van Veen
92301-054	2.1*/14.7‡	gravelly, sandy mud	Gander Bay	49°20.23′N 54°24.63′W	9	van Veen
92301-056	1.1*/5.0‡	mud and gravel	Gander Bay	49°20.81′N 54°26.34′W	11	van Veen
92301-058	not analyzed	pebble	Nickey's Nose Cove	49°41.71′N 55°58.17′W	17	Ponar
92301-059	not analyzed	pebbles and cobbles	Nickey's Nose Cove	49°41.70′N 55°58.17′W	17	Ponar
92301-060	not analyzed	sand and pebbles	Nickey's Nose Cove	49°41.66′N 55°58.17′W	11	Ponar
92301-061	not analyzed	sand and pebbles	Nickey's Nose Cove	49°41.63′N 55°58.13′W	6	Ponar
92301-062	not analyzed	granules and pebbles	Nickey's Nose Cove	49°41.62′N 55°58.13′W	3	Ponar
92301-063	1.4*/6.4‡	pebbly sand	Nickey's Nose Cove	49°41.62′N 55°58.13′W	3	Ponar
92301-064	not analyzed	sand, pebbles, and cobbles	Nickey's Nose Cove	49°41.62′N 55°58.31′W	5	Ponar
92301-065	< 0.1*/57.0‡	pebbly sand	Burgess Cove	49°42.86′N 55°53.72′W	1	trowel
92301-066	3.5*/799.0‡	sand	Burgess Cove	49°42.86′N 55°53.72′W	4	Ekman
92301-067	10.3*/69.7‡	sand	Upwards Cove	42°21.95′N 55°50.81′W	8	Ponar
92301-068	not analyzed	sand, pebbles, and cobbles	Upwards Cove	49°42.20′N 55°55.45′W	0	trowel
92301-069	not analyzed	sand	Upwards Cove	42°23.80′N 55°50.13′W	9	Ponar
92301-070	not analyzed	sand	Upwards Cove	42°22.92′N 55°44.18′W	10	Ponar
92301-071	not analyzed	sand and pebbles	Birchy Cove	49°40.97′N 56°01.21′W	0	trowel
92301-072	not analyzed	pebbly sand	Birchy Cove	49°40.97′N 56°01.21′W	0	trowel
92301-073	not analyzed	sand and pebbles	The Arch	49°41.77′N 55°59.33′W	8	Ponar
92301-074	not analyzed	pebbles and cobbles	The Arch	49°41.76′N 55°59.38′W	8	Ponar
92301-075	1.8*/6.8‡	sand	The Arch	49°41.77′N 55°59.74′W	7	Ponar
92301-076	not analyzed	pebbles and granules	The Arch	49°41.77′N 55°59.36′W	0	trowel
92301-077	not analyzed	sand and granules	Eastern Point	49°41.66′N 55°59.60′W	0	trowel
92301-078	< 0.1*/5.0‡	granules and sand	Eastern Point	49°41.53′N 55°59.78′W	2	Ponar
92301-079	1.0*/5.9‡	sand and pebbles	Middle Arm Spit	49°41.89′N 56°06.16′W	0	trowel
92301-080	not analyzed	sand	Middle Arm Spit	49°41.89′N 56°06.16′W	0	trowel
92301-081	not analyzed	sand	Middle Arm Delta	49°41.95′N 56°08.77′W	0	trowel
92301-082	not analyzed	sand and pebbles	Winterhouse Cove	49°44.12′N 56°01.40′W	0	trowel
92301-083	< 0.1*/5.0‡	sand and pebbles	Winterhouse Cove	49°44.21′N 56°01.44′W	0	trowel
92301-084	not analyzed	pebbles and cobbles	Birchy Cove	49°40.97′N 56°01.21′W	1	scoop
92301-085	not analyzed	sand	Deer Cove	50°01.01′N 56°03.17′W	6	Ponar
92301-086	not analyzed	sand	Deer Cove	50°01.03′N 56°03.20′W	0	trowel
92301-087	not analyzed	sand	Deer Cove	50°01.02′N 56°03.22′W	0	trowel
92301-088	not analyzed	pebbles and sand	Deer Cove	50°01.06′N 56°03.25′W	10	Ponar
92301-089	not analyzed	no sample	Deer Cove	50°01.71′N 56°03.01′W	16	Ponar
92301-090	not analyzed	sand	Lower Green Bay	50°00.21′N 56°05.78′W	4	Ponar
92301-091	not analyzed	sand	Green Cove	49°59.35′N 56°06.68′W	4	Ponar
92301-092	not analyzed	sand	Pine Cove	49°57.98′N 56°08.17′W	4	Ponar
92301-093	not analyzed	no sample	Devils Cove	50°01.92′N 56°01.60′W	5	Ponar
92301-102	0.1*/26.0‡	sand and pebbles	Beaver Cove	49°24.78′N 54°23.48′W	0	trowel
92301-103	0.1*/13.0‡	gravelly sand	Mann Point	49°21.98′N 54°25.85′W	0	trowel
92301-104	0.2*/24.0‡	sand and pebbles	Main Point	49°20.20′N 54°25.60′W	0	trowel
92301-105	1.6*/14.0‡	pebbly, muddy sand	Gander Bay	49°18.98′N 54°26.83′W	0	trowel
92301-106	0.1*/18.0‡	pebbly, granule sand	Horwood	49°28.15′N 54°30.62′W	0	trowel
92301-107	not analyzed	sand and granules	Horwood	49°27.12′N 54°31.97′W	0	trowel
92301-108	not analyzed	sandy gravel and pebbles	head of Dog Bay	49°25.78′N 54°33.55′W	0	trowel
92301-109	2.4*/5.0‡	sandy gravelly mud	head of Dog Bay	49°25.78′N 54°33.55′W	0	trowel
92301-010	not analyzed	sandy gravelly mud	Dog Bay delta	49°25.39′N 54°34.09′W	0	trowel
92301-111	0.9*/5.0‡	muddy sand, granules	head of Dog Bay	49°25.42′N 54°34.05′W	0	trowel
92301-112	0.2*/74.0‡	sand and granules	Dog Bay	49°28.81′N 54°31.46′W	0	trowel
92301-113	not analyzed	pebbles and granules	head of Dog Bay	49°26.94′N 54°33.91′W	0	trowel
92301-114	0.2*/23.0‡	pebbly sand	Clarke's Head	49°17.08′N 54°30.01′W	0	trowel
92301-115	not analyzed	sand and granules	Victoria Cove	49°21.31′N 54°29.50′W	0	trowel
92301-116	not analyzed	sand, granules, and pebbles	Mann Point	49°20.97′N 54°25.30′W	0	trowel
92301-117	0.8*/133.0‡	sand, pebbles, granules	Mann Point	49°20.96′N 54°25.31′W	0	trowel
92301-118	not analyzed	granules and sand	Boyd's Cove	49°27.39′N 54°39.20′W	0	trowel

Appendix 1. (cont.)

Sample number	Au (ppb)	Grain size analyzed	Geographic location		Water depth (m)	Sampler
92301-119	0.3*/86.0‡	sand and pebbles	Boyd's Cove	49°26.95′N 54°38.87′W	0	trowel
92301-120	< 0.1*/5.0‡	sand and granules	Webber Bight	49°36.08′N 54°48.31′W	0	trowel
92301-121	not analyzed	sand	Nickey's Nose Cove	49°41.62′N 55°58.05′W	0	trowel
92301-122	< 0.1*/5.0‡	sand and pebbles	Nickey's Nose Cove	49°41.60′N 55°58.12′W	0	trowel
92042-001	not analyzed	sand and organics	St. John's Harbour	47°32.62′N 52°40.93′W	43	van Veen
92042-002	not analyzed	sand and silt	St. John's Harbour	47°33.69′N 52°40.08′W	93	van Veen
92042-003	not analyzed	sand and silt	outer St. John's Bay	47°33.56′N 52°39.22′W	109	van Veen
92042-004	not analyzed	sand	inner St. John's Bay	47°32.40′N 52°39.74′W	41	van Veen
92042-005	4.7*/98.1‡	sand and pebbles	NW Clam Rock	49°42.82′N 53°53.18′W	89	IKU
92042-007	0.6*/540.0‡	sand and granules	E Fogo Island	49°40.82′N 53°58.06′W	53	IKU
92042-008	3.6*/250.0‡	pebbly sand and shell hash	E Fogo Island	49°40.73′N 53°57.13′W	56	IKU
92042-009	0.2*/68.0‡	sand and shell hash	E Fogo Island	49°40.97′N 53°57.51′W	55	IKU
92042-010	1.0*/69.0‡	shelly sand and gravel	E Fogo Island	49°40.61′N 53°57.07′W	51	van Veen
92042-014	1.4*/5.0‡	clayey silt and gravel	NW Jackson's Cove	49°41.90′N 56°00.44′W	172	IKU
92042-015	0.3*/10.0‡	silty sand and gravel	Nickey's Nose Cove	49°41.93′N 55°58.19′W	43	IKU
92042-016	1.3*/9.0‡	sand and granules	Nickey's Nose Cove	49°42.15′N 55°58.12′W	62	IKU
92042-017	not analyzed	no sample	Green Bay	49°42.82′N 55°55.14′W	41	IKU
92042-018	0.2*/5.0‡	sand and gravel	Salmon Cove	49°42.68′N 55°55.30′W	43	IKU
92042-019	0.3*/5.0‡	sand and gravel	Kings Cove	49°42.91′N 55°54.16′W	47	IKU
92042-020	not analyzed	silty sand	Deer Cove	50°01.33′N 56°03.51′W	57	van Veen
92042-021-1	3.5*/26.0‡	sand and silt	Deer Cove	50°01.32′N 56°03.51′W	57	core
92042-021-2	3.6*/29.9‡					
92042-021-3	37.2*/169.6‡					
92042-021-4	12.2*/21.9‡					
92042-030	1.1*/169.9‡	sand	La Scie	49°59.10′N 55°36.42′W	43	van Veen
92042-031	1.3*/55.0‡	sand, pebbles, and gravel	La Scie	49°59.91′N 55°34.38′W	77	van Veen
92042-034	1.1*/5.4‡	silty sand and pebbles	Wild Bight	49°37.19′N 55°37.48′W	103	IKU
92042-036	0.2*/5.0‡	sand and gravel	Wild Bight	49°37.24′N 55°37.79′W	97	IKU
92042-038	0.5*/5.0‡	sand and gravel	Wild Bight	49°38.16′N 55°38.63′W	86	IKU
92042-040	0.4*/5.0‡	muddy sand and gravel	Wild Bight	49°36.80′N 55°37.52′W	81	IKU
92042-042	3.7*/7.7‡	muddy sand and gravel	Wild Bight	49°36.31′N 55°37.19′W	97	IKU
92042-044	0.5*/5.0‡	sand and pebbles	Wild Bight	49°36.63′N 55°36.89′W	80	IKU
92042-046	0.2*/15.0‡	sand and pebbles	E Cape Fogo	49°46.06′N 53°46.26′W	107	IKU
92042-048	not analyzed	sand	E Cape Fogo	49°25.29′N 53°48.38′W	119	IKU
92042-051	0.7*/32.0‡	sand, shells, and pebbles	E Cape Fogo	49°44.25′N 53°50.90′W	107	IKU
92042-052	1.7*/120 ‡	sand and pebbles	E Cape Fogo	49°39.71′N 53°53.63′W	76	IKU

† S Surface sample
§ M Middle sample
• B Bottom sample
* Head grade of Au assuming no gold concentration in the heavy-mineral concentrate float
‡ Head grade of Au assuming a gold concentration in the heavy-mineral concentrate float